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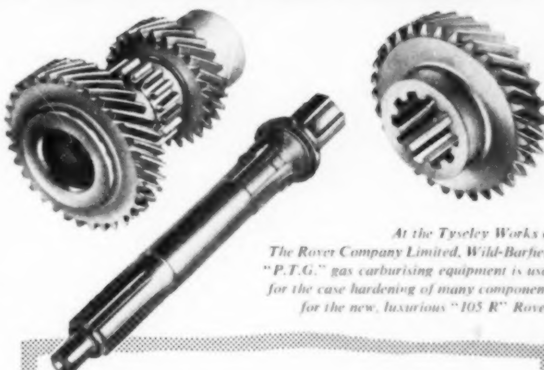

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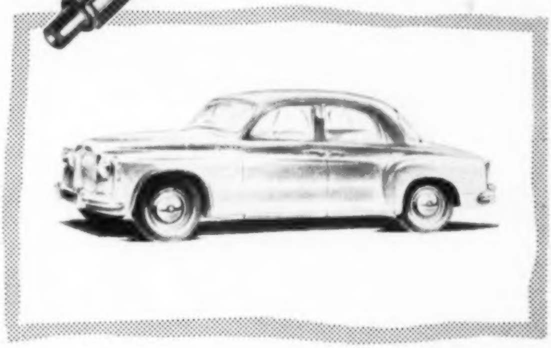

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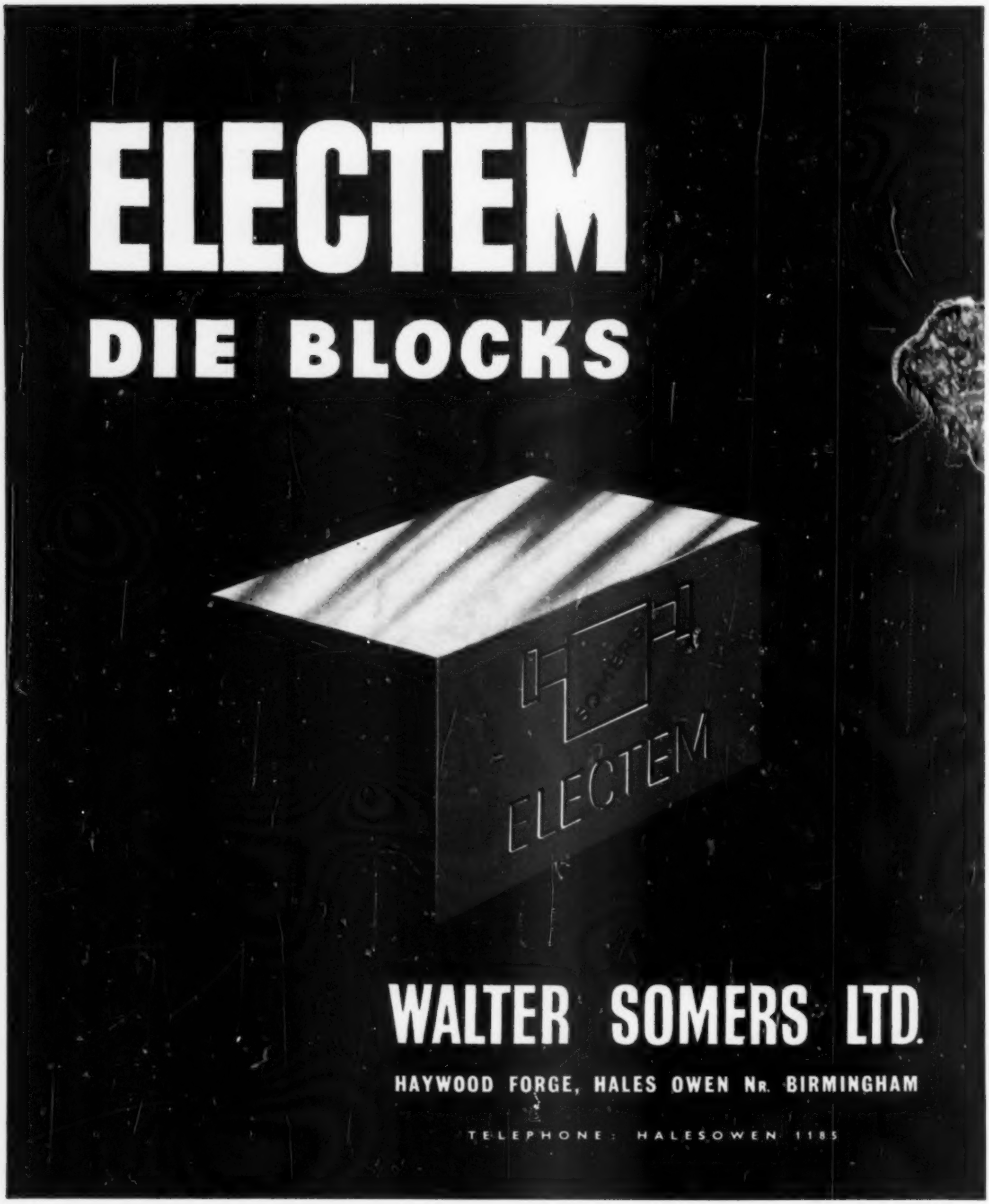
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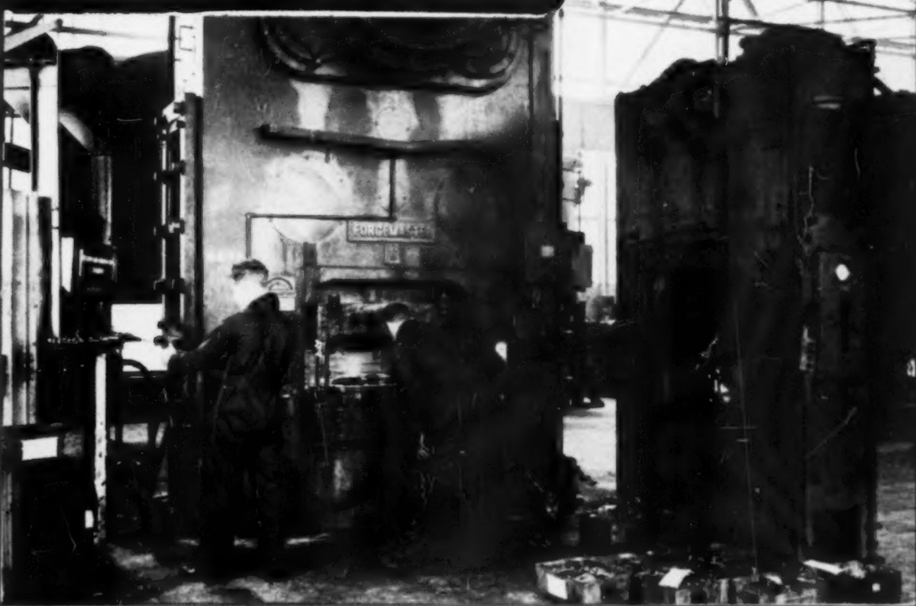

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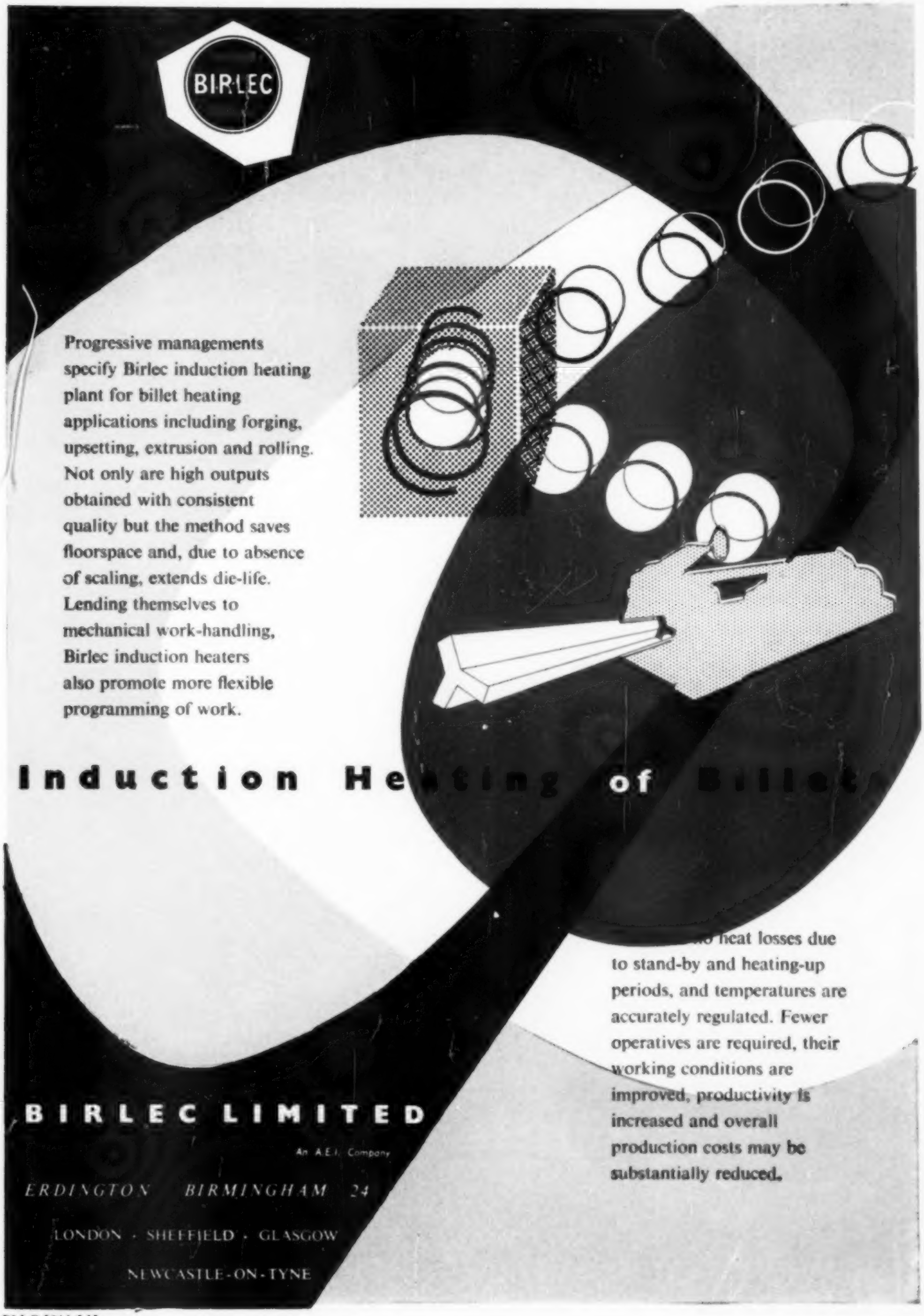
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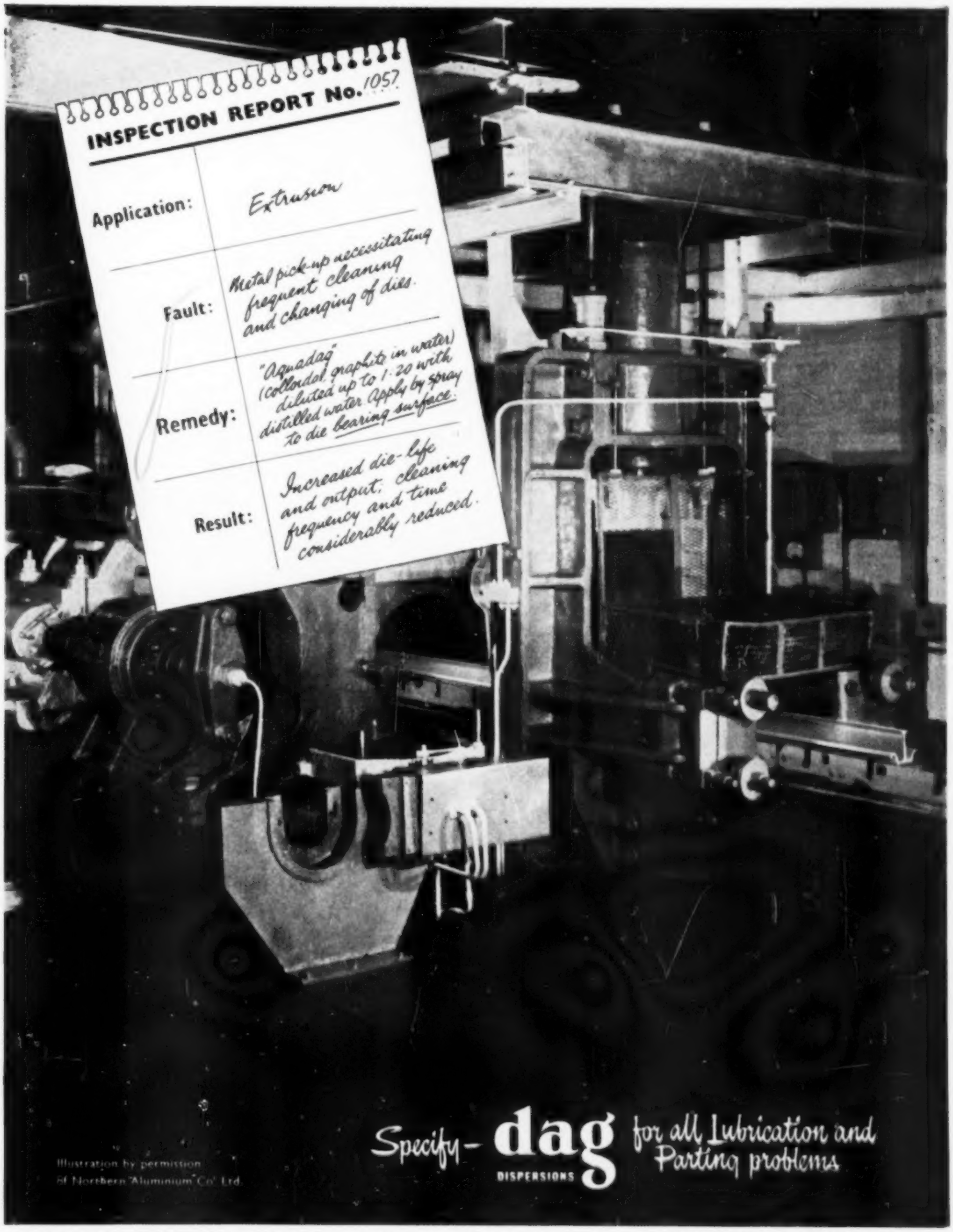
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CONTENTS

This Journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

Page

Trickery

WHEN he opened the new Central Research Laboratories belonging to the Broken Hill Proprietary Co. Ltd., of Australia, last March, Sir Charles Goodeve, the director of BISRA, delivered an address on the subject of research and the future of steelmaking. According to the text of this address appearing in 'BHP Technical Bulletin,' October, 1957, Sir Charles, discussing the steelmaking process, said that he was '. . . astonished at the number of tricks steelmakers have learned in order to carry out a series of simultaneous reactions which, according to the chemists, should more easily go in the wrong directions.' Thinking over the significance of this remark we have been surprised to realise in how many cases a new technical advance in metallurgy has in fact depended upon the successful carrying out of some 'trick' of this nature.

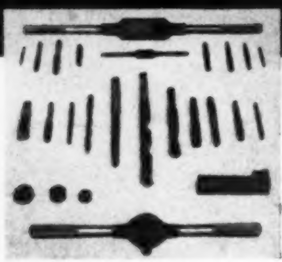
Confining ourselves to steelmaking for the moment, it is apparent that a large number of experts in Western Germany, for example, are hard at work perfecting various ways of carrying out one very important trick, namely, making an oxygen-conversion steelmaking process proceed in such a way that up to 2% of phosphorus may be eliminated from the metal substantially before the carbon has been oxidized. They desire to do this because it has been established that the high nitrogen content of basic converter steels is largely taken up during the 'afterblow,' when in normal practice the phosphorus is oxidized *after* the carbon has all been removed. Such a state of affairs is the chemically 'normal' one since the free energy of formation of P_2O_5 at steelmaking temperatures is less than that of CO.

But this order of oxidation can be reversed, and for many years, of course, has been reversed every day in the basic open-hearth furnace. The trick can be carried out because molten iron can carry dissolved oxygen to an extent some ten times greater than that theoretically needed to cause the oxidation of carbon without necessarily causing this reaction to be completed. German experimenters are now reaping considerable benefits from further practical applications of this device, a process which, unfortunately, Sir Charles Goodeve declared some seven years ago (*Revue de Metallurgie Memoires*, 1951, 329-335) was not likely to be feasible!

Turning to wider fields, it is not altogether incorrect to regard the whole business of the heat treatment of steel as being based upon something of a trick. The relationship between iron and carbon and the formation of ferrite, pearlite, and cementite are governed by a fundamental physico-chemical law—the Phase Rule—which dictates precisely what the system will contain under equilibrium conditions. But because diffusion in the solid state is slow it is relatively easy to force the system out of equilibrium and, so to speak, play tricks on the Phase Rule.

In the non-ferrous field an example of an important metallurgical advance being based upon a trick has been mentioned in these pages recently, namely, the new blast-furnace process for zinc production, which depends for its operation on a 'shock-chilling' technique for condensing zinc from a gas containing 8-10% CO_2. Under equilibrium conditions this is impossible, but by accelerating the operation we can once again cheat the laws of physical chemistry.

The paper describing this new invention was recently presented for discussion to the Institution of Mining and Metallurgy. It was disturbing in the extreme, however,



THE NEWER METALLURGY

D. McLEAN, D.Sc.

National Physical Laboratory, Teddington

A conference, organized by the Institute of Metals, on 'Vacancies and other point defects in metals and alloys,' was held recently at the Atomic Energy Research Establishment, Harwell. Dr. McLean discusses the background of the subjects treated at the conference, and describes the papers which were presented

IT is now widely realized that local disturbances in the crystalline perfection of metals and alloys vitally affect their behaviour. Besides the disturbance known as a dislocation the existence of others has begun to be appreciated in recent years. Some of these have been recognized to be present in ionic crystals for a long time, and are well known to physicists and chemists working with such materials. The recent appreciation of their occurrence in metals is based mainly on two things.

Bombardment with nuclear particles, as occurs in nuclear reactors, produces them in solids, and the solid properties change correspondingly. Some important metallurgical examples are that the tough-brittle transition temperature of steel is raised, the hardness is increased, and internal cavities may be produced. Another example is provided by the recent Windscale incident, which occurred when the temperature of the Windscale reactor was raised in order to anneal out the defects that had been produced in the graphite core by bombardment, and was connected with the energy released as the defects disappeared during this operation. The other reason for the present interest is that the relation between atomic arrangement (or misarrangement) and macroscopic properties is now well enough understood for an intelligent interest to be taken in these new phenomena. It was with this background that a conference on 'Vacancies and other point defects in metals and alloys' was organized by the Institute of Metals and held on December 10 in the excellent Cockcroft Hall of the Atomic Energy Research Establishment, Harwell.

Lattice Defects—Vacancies

Before describing the conference a brief account of the lattice defects that were chiefly discussed may not be out of place. The most ubiquitous is the vacancy, or empty lattice site. These have really been known to metallurgists for a long time as they are produced when zinc is volatilized from brass. The zinc volatilizes faster than the copper atoms can readjust themselves to fill the lattice sites made vacant, and some empty sites are left.

The behaviour of a vacancy closely resembles that of a solute atom, for both constitute irregularities in the lattice, and this is what gives them their effect. Moreover, vacancies can diffuse through the lattice. Strictly speaking, of course, it is the adjoining atoms that move, but one can conveniently and without error speak of the vacancy diffusing. Using this terminology, vacancies do, in fact, diffuse much more readily than solute atoms do, because these only move when a vacancy comes into an adjoining position which the solute atom can then occupy. Significant diffusion of vacancies occurs in a metal such as copper below 0°C.

Associated with a vacancy is an energy of formation Q, in practice about 1 eV arising for example from the lattice distortion around it. By Boltzman's law, the concentration of vacancies present in thermal equilibrium is $c = \alpha \exp -Q/RT$ where T is the absolute temperature, k is Boltzman's constant and α is a number roughly in the region of unity. When more vacancies are present than corresponds to thermal equilibrium, *i.e.* the metal is supersaturated with vacancies, if the temperature permits diffusion to take place they tend to precipitate just as solute atoms do in the same circumstances. The vacancies produced by volatilizing zinc from brass behave in this way; a 'precipitate' of vacancies is, of course, a hole, and this is what is seen on a micrograph of brass so treated.

There may, however, be distinctive features about the precipitation of vacancies. The shape of the hole formed should depend on the surface energy of different crystallographic planes. One idea is that the shape is that of a thin plate, the faces of which are close enough to collapse together, leaving an annulus. This annulus transpires on examination to be a ring dislocation which in all probability does not lie in a plane of easy glide, is therefore difficult to move, and so forms an obstacle to other dislocations which do lie in such a plane. This idea has, however, not yet been proved.

Vacancies can be introduced into metals in several ways. One has already been mentioned. Another follows from the equation for the equilibrium concentration above, which shows that this concentration increases with temperature. A

to note that of all those who spoke at this meeting, other than the authors, not one asked questions regarding the development and design of the shock chiller; nearly all the contributors discussed the physical chemistry of the reactions going on inside the blast furnace, reactions which are supremely unimportant compared with those going on outside. A concern with the physical chemistry of metallurgical reactions has been a feature of the post-war years and has much to recommend it. But if the leaders of our technical societies fail to see the importance of tricks which set physical chemistry at nought (something which German steelmakers certainly do appreciate), then the outlook for British technical progress is not good.

'METAL TREATMENT' records with regret the death of Alastair McLeod, head of the metallurgical editorial staff of Industrial Newspapers Limited. He died in Charing Cross Hospital, London, last Friday following an operation. He was 58.

Born in Edinburgh on May 27, 1899, Alastair McLeod received his metallurgical training at Scottish steelworks and came to be acknowledged as one of this country's foremost experts on rolling-mill practice. He had been for many years with Frederick Braby & Company Ltd., Glasgow, when in July, 1937, he became editor of *Sheet Metal Industries.*

At the time of his death he was managing editor of *Sheet Metal Industries, Metal Treatment and Drop Forging*, and *Metal Finishing Journal*, and managing editor (metallurgical) of *Iron and Coal Trades Review.*

His work took him all over the Continent of Europe. His editorial 'beat' could be said to extend from the Norwegian ore port of Narvik to the iron mines of north and west Africa.


Mr. Alastair McLeod

Alastair McLeod was known and esteemed in metallurgical circles in the United Kingdom, in Scandinavia, in France, Belgium, Luxembourg, Holland, Germany, Austria, and Italy. He had never been to the United States, and it was a great disappointment to him that he was unable to present in person a paper on the technical and economic position of European steelmaking today which he prepared for the 1957 annual convention of the Association of Iron and Steel Engineers in Pittsburgh.

He was a Fellow of the Institution of Metallurgists and an honorary vice-president of the Institute of Sheet Metal Engineering, which he was largely instrumental in founding. He was in addition a member of the Iron and Steel Institute, the Institute of Metals, the Institute of Welding, the Institute of British Foundrymen, the Institution of Production Engineers, the Refractories Association of Great Britain, the American Association of Iron and Steel Engineers, and the Electrochemical Society, New York.

His end was sudden. He collapsed in his office and was rushed to hospital for an emergency operation from which he did not recover. His death is a sore blow to his colleagues.

were briefly presented, only a few of which can be mentioned here.

Some New Experimental Results

(*a*) The micrographs shown by Dr. Barnes of copper irradiated with helium nuclei and then heated to provide vacancies which facilitated precipitation of bubbles of helium gas. The location of the bubbles showed rather convincingly that grain boundaries acted as the chief source of vacancies and did not have to be connected to a free surface or to edge dislocations to do this.

(*b*) Vacancies, and perhaps interstitials, on 'ageing' can produce two kinds of hardening, one similar to precipitation hardening and one suggestive of dislocation locking.

(*c*) Further evidence that work hardening in fatigue, at any rate when the fatiguing is done at room temperature, owes much to the generation of points defects.

(*d*) Further evidence that a strain of amount E % increases the rate of diffusion by the same amount as would a concentration of 0·1 E % of vacancies.

(*e*) Results of irradiation experiments, apparently self-contradictory, which go to show that irradiation produces some results beyond present understanding.

Not many of the new, or rather newly appreciated, effects of point defects are of great direct practical significance, although some mentioned earlier certainly are. What is chiefly coming out of these new studies is a deeper understanding of the extraordinarily complex behaviour of metals. Metallurgy is an ancient trade, with five thousand years of practice behind it. Metallurgical science is hardly 50 years old, but has, and is, making up this immense leeway at a tremendous rate. One may begin to hope that before long this deeper understanding will help to make new metals for old and new uses.

Titanium-clad Carbon Steel Sheets

Vacuum Furnace Brazing Process

BY special adaptations of vacuum-furnace brazing carried out by Stanford Research Institute, Menlo Park, California, it has been demonstrated that ductile, bimetallic plates in large sizes, including titanium-clad carbon steel, can be formed and welded into a variety of useful shapes and structures. Hitherto, according to R. C. Bertossa writing in *Iron Age*, October 31, titanium and its alloys have excited little interest in situations demanding high resistance to corrosion by sea water and other chloride-containing media at low temperatures. The use of titanium alone was out of the question on account of cost, and no method had been devised for applying a thin, corrosion-resistant layer to a cheap, strength-giving material like carbon steel. Two basic problems were faced in developing new cladding techniques. One was the fact that all high-temperature heat treatments have to be conducted so as to afford a high degree of protection against atmospheric gases coming in contact with the titanium, as even minute quantities of oxygen, nitrogen or hydrogen can contribute to embrittlement. Further, titanium reacts rapidly with many other metals and alloys, and intermetallic compounds formed are almost always of low ductility. This closely restricts the number of brazing alloys which can be used. Finally, carbon steel is one of the metals which forms brittle intermetallic compounds with titanium.

Inert-gas and High-vacuum Brazing

Inert-gas protection employing argon or helium during the entire brazing, heating, soaking and cooling cycle will produce ductile, high-temperature brazed joints between titanium and carbon steels. But inert-gas brazing to be satisfactory required very high-purity gas with an extremely low moisture content. Although, as the author states, this method has been successfully used, vacuum brazing now appears most advantageous because there is less chance of contamination from atmospheric gases and moisture under relatively high vacuum. Moreover, high-vacuum conditions rapidly remove adsorbed and occluded gases which are evolved from metals during high-temperature brazing, and this results in greater freedom from porosity in the bond and minimizes the danger of contaminating the protective atmosphere with the evolved gases. High-vacuum conditions also deoxidize some metal interfaces, carbon steel being one, at elevated temperatures, markedly increasing wettability and flow of brazing metals and/or alloys for these surfaces.

Good Bonding without Flux

Brazed joints were made under high vacuum at temperatures ranging from 1,500 to 1,810°F. (approximately 845 to 990°C.), without brazing fluxes; yet the resulting bonds have been complete, uniform and essentially free of gas cavities and other discontinuities. A relatively equiaxed grain structure can be obtained by brazing at 845°C. with silver-copper eutectic brazing alloy with or without lithium. An acicular martensitic-appearing structure results from brazing with higher-temperature silver-manganese alloy and fine silver. Specimens were rapidly cooled from brazing temperatures. Results of micro-hardness tests on the titanium-clad layer showed little difference in hardness between the acicular phase and the equiaxed alpha-annealed titanium. Micro-hardness traverses over cross-sections of the composite clad plates confirmed the satisfactory ductility of the interfacial alloys and bonds.

Since titanium and carbon steels form intermetallic compounds which can be quite brittle, ordinary methods of welding dissimilar-metal clad plate materials cannot be used. The carbon steel backing must be thick enough to meet the design stress by itself. The titanium-clad layer is permanently, completely and strongly bonded to the carbon steel base plate; but, states the author, it should be used in design only as a corrosion-resistant layer and not as a stress-carrying member. The titanium portion of the weld must be applied in the form of a cover strip wider than the weld gap so that it can be inert-gas welded to the titanium layer.

supersaturation can therefore be quenched in, a process exactly analogous to that of quenching in a solute supersaturation. And just as with age-hardening alloys, on ageing the vacancies cluster or attach themselves to dislocations and produce vacancy age-hardening. They are also produced by irradiation and by cold working. Several mechanisms by which they can be produced during cold work have been thought of, but which are the significant ones in practice is not yet known.

Interstitial Solvent Atoms

The other point defect that was much discussed was the interstitial solvent atom, *i.e.* a solvent atom occupying a similar position in the lattice to that of carbon in iron. Apart from geometry, two features distinguish this kind of defect from a vacancy. One is that, with the possible exception of the alkali metals, there is so much lattice distortion around an interstitial solvent atom that a large amount of energy is associated with it, of the order of 4 eV. This has the result that an insignificant number can exist in thermal equilibrium even near the melting point, and there is no question of quenching-in interstitials.

The other feature is that an interstitial is more mobile even than a vacancy and diffuses at temperatures in the region of 50°K. The effect of interstitials on properties should be qualitatively similar to that of vacancies, but as regards mechanical properties there is not yet much experimental evidence that singles them out. Interstitials are produced by irradiation with either nuclear particles or fast electrons, the impact of both these being powerful enough to knock atoms into interstitial positions, and presumably also during cold work.

Papers Presented at the Conference

Turning now to the conference itself, six papers were presented. The first, dealing with the effect of point defects on mechanical properties, was by Dr. A. H. Cottrell. In this, some examples of the effect of irradiation on mechanical properties were described. The largest effect in non-fissile materials is probably the 50°C. or more rise in the tough-brittle transition temperature that can be evoked in steel. The mechanism and annealing out of 'radiation damage' was discussed. The effects of quenched-in vacancies, their ageing and annealing behaviour, the production of vacancies during cold work, the detailed mechanism by which vacancies produce a hardening effect, and the evidence that much of the hardening in fatigue arises from point defects generated during the fatigue, all were surveyed.

The second paper, by Dr. Broom and Mr. Ham, collects the experimental and theoretical information about the numbers of vacancies, interstitials, and dislocations present under different conditions, their energies and their mobilities. Information was gathered from magnetic and thermoelectric effects, from measurements of energies released on annealing and from density changes, but perhaps chiefly from measurements of electrical resistivity, for vacancies increase the resistance just as do foreign atoms. Using a calculated value of the increase in electrical resistance produced by a given vacancy concentration, from the measured increase a value for the actual concentration is found. Similarly, a value for the actual concentration can be got from measurements of the energy released as vacancies are annealed out. These and other different methods of determining vacancy concentrations present under given conditions generally agree within a factor of a few times. Probably, therefore, vacancy concentrations can be measured with nearly the same accuracy as similar trace concentrations of impurities.

The third paper, by Dr. Lomer, discusses diffusion, and tackled the difficult problem of exactly what happens when solute atoms are present and—as there is a growing tendency to believe—the vacancies attach themselves preferentially to these atoms. Diffusion is a subject which at the moment is growing in complexity. Anyone wanting a lucid account could hardly do better than read this paper. Parenthetically, it may be mentioned that metallurgical practice abounds with instances where the combined effect of several solutes is far different from the sum of their separate effects. In this respect also vacancies show a close resemblance to solute atoms.

The paper by Dr. Pratt describes the effects observed in ionic crystals from point defects. In general, the effects are similar to those in metals, but, on the one hand, the fact that alternate lattice sites are positive and negative combined with the fact that the valency electrons exist in bound states gives rise to additional effects, and on the other hand the transparency of substances such as sodium chloride makes possible visible observation of the interior. Because of this some pilot experiments can be done in a direct way with ionic crystals and guide less direct experiments on metals.

A paper by Williams and Hayfield describes some advanced optical work on surface films, interpreting the results partly in terms of electron levels in the films. The final paper, by the present writer, makes an attempt to use present knowledge of atomic defects to understand modern creep-resistant alloys, and discusses such things as the controlling process in creep, the way in which solutes are effective, and fracture in creep.

A pithy discussion followed the presentation of the papers. Numerous new experimental results

NIOBIUM

Part II: Properties and Applications

J. H. RENDALL, A.R.S.M., B.Sc., F.I.M.

In the first part of this article on niobium, which appeared in last month's issue, extraction from the ores and refining of the metal were dealt with. This second and concluding part discusses properties and applications of niobium, including its use in atomic energy reactors

NIOBIUM is a platinum-white, soft ductile metal. Its physical properties according to McIntosh are given in Table I.[15, 16, 17].

TABLE I.—*Physical Properties of Niobium*

Atomic number ..	41
Atomic weight	92·91
Density at 20°	8·66 g./c.c.
Crystal structure ..	Body-centred cubic
Lattice constant at 20° C.	3·3004 ± 0·0003Å
Thermal neutron cross-section (2,200 m./sec.)	1·1 ± 0·1 barns/atom
Mean specific heat at 0° C.	0·0647 cal./g.
Magnetic mass susceptibility	+ 2·28 × 10^{-6} C.G.S. units
Emissivity	0·37 at λ = 6,500Å
Thermal conductivity (0 to 100° C.)	0·13 cal./cm./sec./° C.
Coefficient of linear expansion	6·89/° C. × 10^{-6}
Specific resistance at 0° C. (0 to 1,600° C.) ..	15·22 micro-ohm cm.
Work function	4·01 V.
Positive-ion emission ..	5·52 eV.

The melting point of niobium is the subject of a separate paper by Schofield[16] included in the Institute of Metals Symposium on the Metallurgy of Niobium. In this paper Schofield states that the generally accepted figure for the melting point is that quoted by Fansteel, namely 2,415°C. Schofield observed with an optical pyrometer the hole in a small specimen which was heated up slowly in a furnace; the specimen was held in such a way as not to be in contact with refractories. Schofield's value for niobium containing about 0·12% of gaseous impurities and 1·9% of tantalum was 2,468 ± 10°C. Schofield suggests that the melting point of pure niobium would not be substantially different.

Mechanical Properties

The most complete and up-to-date figures available are those given by Tottle in the Symposium on the Metallurgy of Niobium and these are summarized in Tables II, III, IV and V. One thing

TABLE II.—*Tensile Properties of Niobium*

Test temperature ° C.	Limit of proportionality, tons/sq.in.	U.T.S., tons/sq.in.	Elongation, %	Young's modulus, lb./sq.in. × 10^{-6}
20	10·8	17·6	49	12·4
300	6·3	15·5	38	8·0
500	6·8	15·9	35	6·4
550	4·7	14·4	24	4·7

TABLE III.—*Effect of Oxygen on Electrical Resistivity and Tensile Properties of Niobium at Room Temperature*

Oxygen content	Electrical resistivity, micro ohm/cm.	Mean Vickers hardness No.	U.T.S., tons/sq.in.	Elongation, %*
0·03	16·25	87	18·35	29·3
0·161	18·79	194	34·1	16·9
0·315	25·67	278	60·9	20·5
0·410	26·59	331	58·6	9·8
0·565	30·60	390	Specimen cracked before test	

* Some specimens broke in grips

TABLE IV.—*Results of Creep Tests on Pure Niobium and Niobium-6¼% Molybdenum Alloy*

Material	Temp., ° C.	Stress in tons/sq.in.	Time required for 0·1% creep	Duration of test, hours	Total creep strain, %	Oxygen content, %	
						Before test	After test
Pure Niobium							
Swaged bar ..	600	4	160	5,519	0·306	0·04	0·021
" " ..	700	3	220	3,335	0·40	0·04	<0·1
Niobium-6¼% Molybdenum Alloy							
As-rolled rod ..	600	4	20	600	0·22	—	—

Ceramic Fuels for Nuclear Reactors

Part of the 1957 Ceramic Congress, organized by the Association Belge pour Favoriser l'Etude des Verres et de Composes Siliceux, and held in Brussels last September, was devoted to atomic energy applications of ceramics. Three of the contributions are summarized here

DISCUSSING ceramics versus metallic fuel elements in nuclear reactors, P. Murray and J. Williams, A.E.R.E. (Great Britain), pointed out that at Calder Hall the fuel used was natural uranium metal containing 0·7% U_{235}. In the future, plutonium and thorium might also be used as fuel materials. The important factors required for fuel materials were: (1) Irradiation stability, (2) thermal stability, (3) compatibility with the construction materials, (4) suitable for fabrication.

Uranium was found to grow at temperatures up to 450°C., although this could be limited by decreasing the grain size by β quenching. At about 600°C. and at high 'burn-ups' of 0·1%, large increases in volume took place due to nucleation of xenon and krypton gases. Also both uranium and plutonium showed complex phase changes, with the result that they had very complicated expansion curves.

Ceramic fuels were much less complex and were compared in Tables I and II.

TABLE I.—*Reasons for and against Uranium Oxide (UO_2)*

In favour	Against
High melting point, 2,800°C.	Density 60% of uranium metal
Simple structure with no dissociation below 2,000°C.	Low thermal conductivity
Better irradiation behaviour	Sensitive to thermal shock
Resistance to water corrosion	

TABLE II.—*Reasons for and against Uranium Carbide (UC)*

In favour	Against
Density higher than UO_2 at 13·6	Less favourable than UO_2 with regard to reactions with coolant gases
High thermal conductivity	
High mechanical strength	
Can be fabricated into high density cermets	

The thermal shock and thermal conductivity difficulties of UO_2 might be overcome by dispersing in a metal matrix. By hot extrusion it was possible to fabricate 50 to 60% by volume of UO_2 in steel. It was also possible to produce a BeO-UO_2 ceramic.

Uranium Dioxide

The preparation of UO_2, stated E. Barnes, J. Williams and P. Murray, A.E.R.E. (Great Britain), in their paper on science and technology of uranium dioxide, was usually carried out by reduction of higher oxides in hydrogen. The reaction was very sensitive to the particle size of the material. When UO_2 had a particle size below 0·5μ it would readily oxidize. At temperatures below 100°C. oxygen was taken into interstitial positions in the lattice. Above that temperature, higher oxides began to be formed and might be intermediate between $UO_{2\cdot0}$ and $UO_{2\cdot5}$. If these oxides were heated to above 300°C. the end products were the stable phases $UO_{2\cdot0}$ and $UO_{2\cdot5}$. If UO_2 was heated in air a 30% volume expansion occurred with the formation of U_3O_8. Differential thermal analysis curves of this reaction showed three peaks between 200 and 450°C.

The first experiments were carried out using American material and it was found that samples pressed at 7 to 10 tons/sq. in. would give green densities of 6·0 and after sintering in vacuum at 2,000°C. about 9·0. When this oxide, which was shown to be $UO_{2\cdot04}$, was heating in air before use it was found that the sintering improved.

British-made oxide then became available which was $UO_{2\cdot13}$. It was found that this material would give densities of 10·0 at a sintering temperature of 1,450°C. in argon. It was found that the surface area of the British material was greater than that of the American, and it had now been shown that the non-stoichiometric nature of this material assisted the sintering. It had also been found that, when hot pressing in graphite dies, this non-stoichiometric material required a higher temperature to obtain a certain density than that required for sintering in argon.

Sintering of Uranium Oxide

In Sweden the use of UO_2 as a fuel for reactors was becoming of great interest, stated V. Runfovs, Aktiebolaget Alumenergi (Sweden), discussing methods of sintering uranium oxide. In 1960 an 80-MW. project was scheduled and would use UO_2 as fuel. It would be moderated and cooled with heavy water. UO_2 was very good for this purpose since it showed high resistance to corrosion by heavy water. The amount of fission gases formed were lower than with other fuels, but it was necessary to keep the permeability low in order to keep these fission gases under control. Samples of oxide at 6 tons/sq. in. gave a green density of 5·8. It was necessary to sinter to above 1,800°C. to get a good density and the process used tended to form uranium carbides on the surface. These had to be removed since they reacted with water. Very good crystal growth was found with this material when sintered to 2,000°C.

only used when the temperatures are low and the irradiation times are short.

Physical Properties: The melting point of the canning material should be well above the operating temperature of the atomic pile. The thermal conductivity of the can should be high and the linear expansion of the can should be similar to that of the uranium, otherwise there is a risk of premature failure of the can. The combination of properties, thermal conductivity k, coefficient of expansion α and Young's Modulus E should combine to give a low value of the parameter $E\alpha/k$ in order to give a high resistance to thermal shock. The vapour pressure of the canning material should be low at pile temperatures.

Chemical Properties: The ignition temperature of the canning material should be high and the resistance to corrosion by water should be good as spent cans from the pile may be stored in water for considerable periods until their radioactivity diminishes.

Compatibility: This is one of the most important criterions for the selection of canning materials. The material of the can must not dissolve in or form low melting point compounds with either the uranium or with the liquid coolant metal outside it. It may be sufficient if the can develops a film which prevents and sufficiently slows down further reaction with the uranium or the liquid metal coolant. The presence of impurities in the coolant may affect the compatibility of the can with the coolant.

Niobium, since it fulfils many of these requirements, is suitable for use in liquid-metal cooled reactors. Its strength in the unalloyed condition is fairly high and the possibility of improving it by alloying exists. Its ductility, provided that its gas content is low, is good. Its melting point, 2,468°C., is high. Its thermal conductivity is 1/7 that of copper. It is not likely to suffer from thermal shock. With regard to chemical properties it is not easy to ignite and its resistance to corrosion is very good. Tests for compatibility with uranium reported by McIntosh and Bagley[21] show that the resistance of elements of Groups IV*a*, V*a* and VI*a* decreases in the order W, Ta, Nb, Zr, Ti, Mo, thus niobium is the third most resistant. Tests with liquid sodium and sodium potassium alloy showed that niobium had an excellent resistance at temperatures up to 800°C.

In short, niobium, while having no unique properties which fit it for use as a canning material in atomic liquid-metal cooled reactors, possesses a very useful combination of properties.

One use of niobium which has recently been reported is the addition of 15% of it to uranium to confer resistance to hot water attack.[4] Dr. G. L. Miller said at the Institute of Metals Symposium that he believed that this was the major use of niobium for atomic energy in the United States.

Niobium in Austenitic Stainless Steels

The austenitic stainless steels were developed by Strauss and Maurer in the Krupp laboratories in the period 1909 to 1912. The main advantage of these steels over other types of stainless steels is their amenability to cold working processes such as deep drawing. In the early industrial use of austenitic stainless steels, their high degree of general corrosion resistance was confirmed, but it was soon found that they were susceptible to a form of intergranular attack. This attack usually took place in the vicinity of welds but occasionally occurred in vessels which had not been welded. The earliest name for the attack was ' weld decay ' but is now generally called ' intercrystalline corrosion.' The discussion of the phenomena which follows is largely based on the book by Keating.[22]

The solubility of carbon is much greater in the austenite phase of stainless steels than it is in the ferrite phase and the solubility of carbon in austenite increases with increase in temperature. If the alloys are cooled extremely slowly from temperatures at which all the carbon is in solution and also are held at certain temperature for sufficiently long periods, most of the carbon will separate from solution leaving only about 0·02 to 0·03% dissolved. The carbon thus formed consists of moderately large crystals and the final distribution of chromium in the steel is fairly uniform.

In general, however, austenitic stainless steels contain about 0·12% carbon and this is retained in solid solution under normal conditions of cooling. If the steel is now heated within the temperature range 550 to 750°C. the carbon is precipitated, the majority of it in the grain boundaries as a carbide containing about 15 to 18 times as much chromium as carbon. In the temperature range concerned, the rate of diffusion of chromium is much slower than that of carbon; the result is that the grain boundaries are denuded of chromium and the grain boundaries become, in liquid corroding solutions, anodic to the rest of the metal. Rapid corrosion takes place at the boundaries which in time can lead to complete disintegration of the metal into separate crystal grains. The association of this type of intercrystalline attack with welding is due to the fact that a narrow zone one each side of a weld will be heated to within the temperature range 550 to 750°C., but any other treatment which heats the metal to within this range will also tend to cause this type of corrosion.

which must be always borne in mind is the very large effect that small amounts of gaseous impurities have on the mechanical properties of niobium. This effect is particularly important in creep testing since pick-up of gaseous impurities during creep testing may increase the hardness from 158 to 194 VD before test to 244 to 320 VD at the end of the test.[25]

It appears from the results given in Table IV that the addition of molybdenum decreases the creep resistance.

TABLE V.—*Effect of Alloying Elements on Mechanical Properties of Niobium at Room Temperature*

Alloy	U.T.S., tons/sq.in.	L.P., tons/sq.in.	Elong. %	V.P.N.
5% Mo	26·4	21·8	12·3	150
6½% „	37·6	—	15·0	150
10% „	31·0	24·2	8·5	167
5% W	26·0	21·7	11·7	145
5% „	19·9	13·3	8·9	111
10% „	29·7	25·8	9·9	191
2% Zr	20·0	14·1	11·5	94
10% Ta	28·7	20·8	19·8	74
2% V	24·9	18·9	11·2	123
5% Ti	24·7	21·7	15·3	147
1% Pt	19·4	14·05	13·2	94
Niobium*	18·35	12·6	29·3	87

* As used in proportion of above alloys

Traces of impurities in the alloying elements, *e.g.* in the zirconium and vanadium, gave rise to serious difficulties in fabrication and testing.

Use in Atomic Energy Reactors [15, 19, 20].

The large anticipated increase in the demand for electricity in the United Kingdom can, because of the apparent impossibility of increasing the output of coal, only be met either by a great increase in the import of fuel oil or by a vigorous development of atomic energy. The disadvantages of the first alternative are only too obvious and so the development of atomic energy is being pressed on with the greatest vigour.

The uranium metal, which is used in the majority of atomic reactors, must be put into a container or, as the jargon has it, must be 'canned.' There are a number of requirements which must be met by the metal from which the can is made and the use to which niobium will be put in the atomic energy programme is as the canning materials used in certain types of reactors.

Atomic energy reactors can be divided into two classes, namely 'thermal reactors' and 'fast reactors.' In the thermal reactor the fuel is dispersed in a material known as a 'moderator,' which slows down the neutrons produced by the fission of uranium to a low energy so that the chain reaction keeps going by the fission of uranium. The materials used as cans for thermal reactors must have a low-absorption cross-section for thermal neutrons and that of niobium is usually considered to be too high for thermal reactors, though Ball [20] does mention the possible use of niobium in a thermal reactor.

In a fast reactor, neutrons are not slowed down but are allowed to cause fission while they still retain most of the energy with which they are generated. The absence of a moderator leads to an active core of very small volume in which a great deal of heat is liberated. The core of the Dounreay fast reactor is 21 in. high by 21 in. dia. and yet the heat extracted is said to be 60 mW.

This high heat rating requires the use of a liquid coolant. However, a wide choice of canning materials is available because the absorption cross-section for fast neutrons is generally lower than for thermal neutrons; niobium is one of the possible materials and is, in fact, being used in the Dounreay fast reactor.

In service in a reactor, the greatest neutron flux, the highest temperature and the most severe stress and corrosive conditions exist in the fuel element which consists of the fuel and its surrounding can. The can is necessary because uranium is not corrosion resistant and has low mechanical strength. The can also prevents the escape of fission products which might cause serious difficulties if they contaminated the coolant. In addition to strength and corrosion resistance each design of reactor requires a specific combination of nuclear, mechanical, physical and chemical properties in the material used in the can.

Nuclear Properties: In fast reactors the absorption cross-section does not vary much from material to material and does not restrict the choice of materials significantly. However, induced activity as a result of neutral irradiation must be considered and elements which lead to persistent activity in irradiated materials, *e.g.* cobalt, tantalum, antimony and indium must be excluded from the canning material either as deliberate alloying additions and as impurities, since the presence of these elements renders more difficult the problems of handling irradiated fuel elements and of disposing of radioactive waste.

Mechanical Properties: In an atomic pile, because of irradiation and thermal stresses, uranium tends to change its shape and after long periods in the pile, very severe distortion can occur. The can may be designed either as a casing which is strong enough to support the designed stresses to which it is subject but is sufficiently ductile to be able to relieve severe local stresses without failure, or the can be designed to act as a pliable sheathing to the uranium which acts as the load bearing member of the assembly. The latter type of can is

Prevention of Intercrystalline Corrosion

There are three methods of overcoming the corrosion: (i) Cold working the steel before heating in the range 550 to 750°C.; (ii) reducing the total carbon content of the steel; and (iii) adding to the steel elements which form very stable carbides.

Cold Working: This method is of very little practical importance and is dependent on the fact that cold working the austenitic steel in which the carbon is in unstable solution tends to precipitate the carbon in the slip planes. This tendency can be increased by heating the steel for a short time in the range 550 to 750°C. There is thus less carbon available to precipitate at the grain boundaries.

Reduction of Carbon Content: Since the intercrystalline corrosion is associated with the precipitation of carbides, one obvious way of overcoming the trouble was to reduce the carbon content of the steel. Any reduction in carbon content reduces the tendency towards inter-crystalline corrosion and 18/8 chromium-nickel steels with low carbon contents have been successfully used in mild corrosive conditions. However, for practically complete freedom from intercrystalline corrosion, the total carbon content of the steels should be below 0·03%. The production of such steels is dependent on the use of very low carbon ferrochrome. The manufacture of such ferro-chrome has recently become possible and 18/8 steels with less than 0·03 carbon are available. There is, however, even at these low carbon contents a risk of disintegration.

Addition of Stabilizing Elements: If the carbide formed by the element added as a stabilizer is more stable than chromium carbide and a sufficient excess of the element is added there will be no tendency for chromium carbide to form and denude the grain boundaries of chromium. The two elements used for this purpose are titanium and niobium. Titanium was the first element to be successfully used and is the element normally used in the U.K. There has been until recently a tendency in the U.S.A. to prefer niobium-stabilized steels. However, the following figures of U.S.A. production show that this trend has been reversed.

Year	*Type* 321 (Ti-stabilized)	*Type* 347 (Nb-stabilized)
1948	7,528 tons	33,346 tons
1952	70,204 „	13,265 „

For most applications both elements are equally useful for overcoming intergranular corrosion. One of the applications, however, in which niobium-stabilized steel is better is resistance to boiling 65% nitric acid. This concentration of acid is widely used in the U.S.A. in the Huey Test for the detection of intercrystalline corrosion in 18/8 steels; thus the belief was widely held that titanium stabilized steels were generally inferior. In fact, the inferiority was only shown when subject to a limited number of corroding liquids. Other advantages of niobium stabilization are—(i) titanium is more easily oxidized than niobium during steel making and this leads to a greater risk of material of incorrect composition, and (ii) niobium is much more satisfactory than titanium in stabilized 18/8 welding rods since it is impossible to control the loss of titanium in the arc and, in fact, titanium is not used in rods for arc-welding.

Nevertheless, where possible, titanium will be used in preference to niobium since ferro-titanium is cheaper than ferro-niobium (about 7s. per lb. of contained alloy as against 22s.), titanium as an element is extremely common in the earth's crust and there is thus no supply problem, and less titanium is needed (titanium-carbon ratio needed is 4-5 : 1, while niobium carbon ratio is 8-10 : 1).

Heat-resisting Alloys

One of the major uses of niobium is in heat-resisting alloys, especially those known in the U.S.A. as 'super-alloys' which are austenitic alloys based on iron, nickel or cobalt and containing chromium and aluminium and the carbide forming elements molybdenum, tungsten, niobium and titanium. It was probably this use of niobium which led to the stockpiling of niobium by the U.S.A. Government between 1951 and 1955. Niobium is also a constituent of a number of British ferritic high-temperature alloys such as H46 and Rex 448. Niobium, however, is not present in the well-known Nimonic series of alloys.

Niobium is an element which forms very stable carbides and it is probably that a fine dispersion of these improves the creep strength in alloys containing niobium, but the exact details of mechanism do not seem to be known. Nor does it appear that niobium has any essential function in heat-resisting alloys since the Nimonic alloys do not contain it. One reason for adding niobium to heat-resisting alloys may be what is known as the 'complexity effect' which shows itself in the fact that an addition of three and more different carbide-forming alloys has a greater strengthening effect than the same amount of any one of them.

Details of a number of heat-resisting alloys containing niobium are given in Table VI, the right-hand side of the table giving a few typical results of creep tests which show the strengths that are obtained. The whole subject of high-temperature creep-resistant alloys is very complicated and little useful information can be given in a short article.

Another type of heat-resistant alloy which contains niobium is the 'cermet' mixture of ceramic and metal. The most developed of these alloys is a type containing carbides as the ceramic and nickel,

cobalt or chromium or a combination of these metals as the matrix. One group of materials of this type is the cemented TiC-TaC-NbC carbides made by Kennametal, Inc., under the name Kentanium.[26] These contain 10 to 30% nickel or cobalt as the binder or matrix metal and the carbides are a mixture of TiC, TaC and NbC. It is claimed that certain of these alloys have a stress-rupture strength 70% above that of Inconel X at 870°C.

Alloys of Niobium

Owing to the small interest shown until recently in niobium very few constitution diagrams of niobium are available. McIntosh [15] shows ten which are all that are available; these are the diagrams of niobium with Ti, Zr, V, Ta, U, Mo, W, Fe, Co and Ni and even three of these are largely conjectural. McIntosh also speculates on the form of the unknown constitutional diagrams and the following table is taken from his paper:

Systems known to form intermetallic compounds	Systems likely to form intermetallic compounds	Systems likely to exhibit appreciable solid solubility
B, C, N, O, Al, Cr, Mn	Be, Ru, Rh, Pd, Re, Os, Ir, Pt	Ag, Al, An, Cr, Ru, Rh, Pd, Hj, Re, Os, Ir, Pt

Strengthening brought about by alloying is due to two mechanisms, solid-solution hardening and precipitation hardening. There is, at the moment, insufficient information available to enable the most promising alloying elements to be selected, though, no doubt, a great deal of research is being done.

The addition of alloying elements to niobium to

TABLE VI.—*Examples of Heat-resisting Alloys Containing Niobium*

Name	Composition, %								Use	Results of creep tests		
	C	Si	Mn	Cr	Ni	Fe	Nb			Temp., °C.	Load, tons	Result, 1,000 h.
326 steel Firth-Vickers	0·3	0·8	3·0	16·5	17·5	bal.	2·5	3·0 Mo 7·0 Co	Large turbine discs and rotor forgings	700 700	8·5 9/11·5	0·5% creep Fracture
19-9 W -Mo	0·10	0·50	0·60	19·0	9·0	bal.	0·40	0·40 Mo 1·25 W 0·35 Ti	Gas turbine and super-charger discs, gas turbine ducting and blades	704 760	10·5 6·0	Fracture Fracture
Gamma-Cb	0·40	0·46	0·84	15·0	24·7	bal.	1·90	4·39 Mo 0·036 N	Supercharger discs	650	16·6	Fracture (hot-cold worked)
G. 18 B Wm. Jessop	0·41	1·13	0·76	13·4	13·3	50·0	3·38	1·80 Mo 2·72 W 10·3 Co	Gas turbine discs, blades, large rotor forgings	700	7·8 12·0	0·5% creep Fracture
Multimet or N.155 (low carbon)	0·20	—	—	18·0/ 22·5	18·0/ 22·0	—	0·75/ 1·50	2·75- 3·75 Mo 2·0- 3·0 W 18·0- 22·0 Co 0·10- 0·20 N	Gas turbine discs and blades	649 815	21·9 7·2	Fracture Fracture
Inconel "X"	0·04	0·40	0·50	15·0	73·0	7·0	1·0	2·5 Ti 0·7 Al	Gas turbine discs and blades	649 815	30·8 8·0	Fracture Fracture
S. 816	0·40	0·60	1·30	20·0	20·0	bal.	4·1	3·8 Mo 4·2 W 42·0 Co	Gas turbine blades	649 649 815 815	14·7 20·1 2·7 7·8	0·5% creep Fracture 0·5% creep Fracture
G. 32	0·30	0·30	0·8	12·0	19·0	bal.	1·2	2·0 Mo 45·0 Co 2·8 V	Forged gas turbine blades	800	11·0	Fracture

From 'Heat Resisting Steels and Alloys,' by C. G. Conway. George Newnes Ltd., London, 1953.

increase its resistance to oxidation is also an important subject of research but again no very definite information is available, though there are rumours that alloys resistant to oxidation at high temperature have been developed. Until these are developed niobium is unlikely to be satisfactory as a base for creep-resistant alloys used in oxidizing atmospheres. Some figures for the mechanical properties of niobium alloys are given in the Section on Mechanical Properties.

Miscellaneous Uses

5 % *chromium steels:* Niobium, although much more frequently titanium, is sometimes added in sufficient amounts to combine with all the carbon in these steels. The object of the tying-up of the carbon is to prevent air hardening of the steels during cooling from temperatures above the critical range. These 5% chromium steels are not stainless but they have a very useful corrosion resistance. They are extensively used for tubes in oil refineries.

Hard Metal Tools: Tantalum carbide which often contains a fair proportion of niobium carbide is added to some grades of tungsten carbide tools. The niobium carbide is probably due to the use of mixed ores for the production of the metal rather than by deliberate addition. The addition of tantalum carbide is claimed to improve the resistance to ' cratering ' without impairing the toughness of the tool, to increase the hardness and oxidation resistance of the tool.

Typical percentage compositions[27] of tools are:

W	Ta	Nb	Co	C
80·7	1·4	0·6	11·9	5·4
68·9	6·7	1·6	10·7	6·7

Grain Refinement in Cast Aluminium Alloys: Titanium is added to a number of aluminium alloys in order to give grain refinement. Niobium can be used in place of titanium and is permitted in B.S. 1490 for alloys, L.M. 22, 22/W, 23 and 23P.

Future Outlook for Niobium

It will be seen from the data given in this paper that niobium has properties which would make it a desirable metal for many purposes. The three main reasons why its use is so restricted are, first, that it is rare in nature, second, that it is difficult to separate from tantalum, and, third, it is difficult to convert to ductile metal. It is thus a very expensive material, fabricated niobium costing about £70/lb.

This cost does not bar its use in atomic energy applications, since if only small amounts are needed and no other material is as suitable, its use will be economic. The use of the metal in atomic energy production may well lead to increased supplies and lowered cost.

Niobium is used in heat-resisting alloys since the ferro-niobium used is much cheaper than pure metallic niobium owing to the fact that it does not need to be free from tantalum or to go through the very expensive sintering process. At one time, the chief bar to its use was shortage of supply, but this is probably no longer true and the metal may be used whenever the advantages justify the cost. Its use as the major metal in heat-resisting alloys depends on the development of an alloy, resistant to high temperature oxidation. If strong oxidation-resistant alloys can be developed, then price and supply will decide whether or not they are used.

Niobium is very resistant to corrosion at room temperatures, though it is not as good as tantalum. If the development of the pyrochlore deposits and improved methods of refining bring down the price it may be used in place of tantalum in specialized chemical engineering applications.

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DETERMINATION OF HARDNESS THROUGHOUT HEAVY STEEL SECTIONS

IT is common knowledge that large sections of ordinary steel during heat treatment do not harden uniformly from surface to core because, during quenching, heat is not removed fast enough from the centre for hardening to be completed. As a result, micro-structure and mechanical properties on a cross-section vary throughout and impact resistance is reduced below maximum attainable with uniform hardness. Because accurate measurement of impact resistance has not been possible, designers of steel fabrications have either had to over-design, or substitute deep-hardening alloy steels for less expensive carbon steels. The United States National Bureau of Standards has devised a test to overcome non-uniformity in hardening and thus to reduce unnecessary cost of over-designing. The new procedure, reported in *Steel*, October 7, employs a Charpy V-notch impact specimen which has been end quenched by immersion. A series of planes with differing but predictable micro-structures and hardness is formed, these varying with distance from the quenched end. Depth of immersion and quenching medium are predetermined from Jominy data on the same steel. Standard bars are quenched according to ASTM specifications, a hardness survey along the length of the bar being correlated with micro-structures. A graph of hardness plotted against distance from quenched end can be used as soon as the desired hardness or structure is located in the Jominy bar and distance from the quenched end is established.

Series on Heat Treatment

The Heating of Steel for Working and Treatment

F. C. BIRD

This is the second of the course of lectures on 'Modern Trends in the Heat Treatment of Steel,' recently given at the Wolverhampton and Staffordshire College of Technology. The author, who is with Walter Somers Ltd., considers practical questions of heating steel for forging and heat treatment

UNTIL the last 25 years, heating for forging or heat treatment was largely by indigenous fuel. Coal still plays a great, although indirect, part, either as gas or generated electricity. Yet this commodity is now insufficient in quantity for our needs. Known reserves are estimated at present rates of consumption to last but a century more and will grow more expensive owing to the unpopularity of working underground, by the exhaustion of the better seams and by the increased difficulty of winning the remainder. Liquid fuels derived from coal are subject to the same considerations.

Fuel oil, produced from crude petroleum, is a modern substitute hitherto mainly applicable to heating for forging. Here, too, world supplies are not inexaustible. Despite the increased availability resulting from large post-war refineries in the U.K., this commodity is subject to political considerations which must cause circumspection, and the future demands of under-developed countries in Africa and the East are likely to limit supplies and increase the cost. Additional requirements from the industrial nations are to be expected, and home production is limited to a mere 150,000 barrels annually from oil-bearing shale in Scotland.

Sources of Power other than Coal or Oil

There remains electricity produced otherwise than from coal or oil. Our terrain is unsuitable for any substantial contribution from wind power which is, in any case, intermittent, although it has been developed and tried. Barrage schemes may add a small though valuable increment, but cannot equal the importance they have in Sweden. Recent opinion regards electricity from atomic energy as the answer to the problem, but it is not always realized that even accelerated development of such sources of power can only partly relieve the extra demand for conventional fuels during the next decade. Even if the unit cost of electricity from atomic power eventually proves cheaper than that from coal (and it is at present greater) it will be an insignificant price factor for many years.

This sombre picture deserves emphasis, for we have been termed the 'champion fuel wasters of Europe.' A recent estimate allowing for losses in winning, transporting and using fuel, suggested that only 2% of the potential energy in the raw material was represented in the final product.[1] National welfare and the competitive interest of individual firms are here alike, yet except in the larger organizations, anything technical to do with furnaces and heating tends to lie in 'a no man's land' between the engineer and the metallurgist. Mention must be made, however, of advisory facilities, such as the National Industrial Fuel Efficiency Service whose explanatory leaflets and preliminary visits are free, the industrial sections of the respective Divisional Gas Boards, services available from certain of the fuel oil companies and technical advice to be obtained from the sub-areas operating under the various Area Electricity Boards.

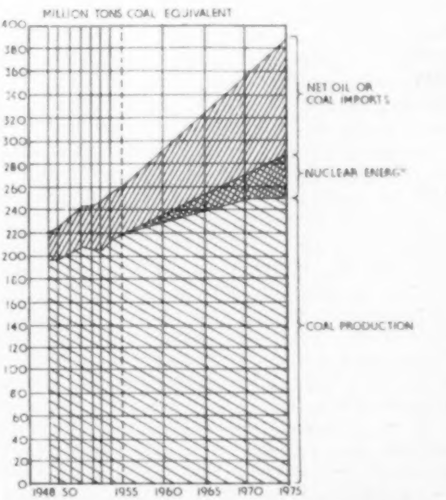

Fig. 1.—Anticipated fuel demands ('Fuel Economy Review')

Conduction indirectly plays an important part in the efficiency of heating by its effect on the rate of heat loss through the furnace walls.

Transfer by Convection: Convection should be considered apart from flame extent and shape, which are properly concerned with radiation. Heating outside a furnace provides the exception, where flame inpingement is utilized. Low-temperature furnaces sometimes have fans within to set up speedy currents, and in other cases the heat is applied outside the stock space, and an external fan circulates the gaseous products of combustion. Convection is here the main factor, but contrary to popular belief, it plays a minor part in most other cases. This is because it can apply only to surfaces in the path between flame tip and exit, or to the currents set up by temperature differences in walls or radiants.

Convective transfer depends not only on the fluid temperature, but also on the speed of the gaseous currents, and in furnaces this rarely exceeds 25 ft./sec., unless assisted. Moreover, the boundary layer of the stream, where the heat transfer takes place, will move at a lower rate than the average speed. This affects not only heat output to the metal, but also heat intake from hotter refractories. Furthermore, the size of the stream, *i.e.* increased space beneath or around the stock, is of little advantage except in a long furnace with an end take-off where substantial cross-sectional area will provide a moving reservoir of heat to maintain the temperature of the boundary layers.

Transfer by Radiation: Radiation is by far the most important method of heat transfer. It has been estimated that for most furnaces involving combustion and for use at temperatures over 1,150°C., direct radiation from flame and gases transfers 54% of the total heat input, re-radiation from walls and roof accounts for 34% and only the remaining 12% is due to convection. In electric-resistance furnaces, it accounts for the whole heat transfer, for the effect of natural convection is negligible. Even a convective fan in such a case is concerned mainly with heat distribution rather than the transfer from element to stock.

Two factors govern the process of radiation. By the Stefan-Boltzmann law, the rate of radiated heat transmission is proportional to the difference between the fourth power of the absolute temperatures of the emitting and receiving entities. This means that the hotter the flame, the quicker will be the heating process, and it is important in comparing flames from different fuels and also in securing the best possible efficiency of heat transfer, obtaining the maximum flame temperature by correct combustion conditions.

The second factor is termed 'emissivity' and is an expression of the power of different substances at the same temperature to radiate heat. Unity factor is ascribed to a theoretically perfect or 'black-body' substance, indeed lamp black (0·97) approaches this closely. Within a furnace, reflection and re-radiation combine to produce approximately the desirable black-body conditions as regards solid surfaces (provided the door is closed), but this is not true of flames which retain their differing factors.

For two flames at equal temperature and maintained volume, the flame with the higher emissivity will radiate faster under similar conditions. This appears to depend on the luminosity due to minute carbon particles derived from the chemical breakdown of hydrocarbons in gas. A similar process takes place from the residue of destructive distillation in the evaporation of minute oil globules or in the combustion of powdered solid fuel.

The luminous aspect of a flame adds greatly to its radiation. In addition to the heat of combustion of the minute carbon particles, flames accept convected heat from the surrounding intimately mixed gases in combustion, and being raised to greater

Fig. 2.—Double-stage induction heater made by Birlec Ltd. Operates at 50 c/s and 3 kc/s, above 700°C. Capacity is 1 ton/h. of 3 by 3 by 6 in. billets

Methods of Heating

In considering such a vast field as heating for forging and heat treatment which extends from needle manufacture to a 250-ton ingot, only a cursory survey can be made of general principles and alternative means.

Heat, a form of energy, can be generated within steel by electrical resistance and induction, or it may be transferred by conduction, convection and radiation.

Electrical Resistance and Induction:—Low-voltage resistance heating, such as is used for welded chain, has a limited application for forging, *e.g.* where a centre section of rod is required to be upset prior to final formation. With larger sections, it is difficult to provide electrodes which can be quickly attached and make good contact to avoid undesired resistance due to scale. High resistance on the contacts can cause local temperature rise, and therefore oxidation, with damage to the input fixtures.

Induction heating utilizes the principle that, if a piece of steel forms the core of a coil in which single-phase alternating current passes, the energy of the induced eddy currents will be released as heat adjacent to the outer surface. Since applications are individual, the input, by means of the coil length, is arranged to balance the rate of conduction to the centre so that an even temperature gradient within 5° is claimed. More could well be tolerated for forging purposes. The time taken for (*e.g.*) a round billet is approximately $(5D)^2$ sec., where D is the diameter in inches. The water-cooled copper tube coil is protected by a refractory lining and provided with skid rails of heat-resisting material. Such coils are usually limited to 5 ft. in length to preserve rigidity. To secure an efficiency of 50%, they should conform closely to the stock shape, which may vary in size within ½ in., but for square billets a cheaper circular coil can be used up to 6 in. dia. Above this size a shaped form is fabricated and also alternative coils used within the installation capacity, if different sizes of billet are required at various times. The frequency governs the depth of heat release—0·5 Mc/s for brazing and thin rod is provided by electronic generators, while 10 and 1 kc/s, often used for steel up to 1½ in. and between 1½ in. and 8 in. respectively, are furnished by motor alternators. For larger sizes, mains frequency of 50 c/s can be used. In this case there is a loss in efficiency when the temperature reaches the Curie point of about 720°C. The cross-section enables it to be tolerated over 8 in. dia., but for intermediate sizes between 1½ in. and 8 in. dia., overall efficiency demands a dual and successive coil arrangement whereby 50 c/s is used up to 650°C., and a higher frequency employed afterwards.

For hardening, a variety of arrangements are possible. For example, pliers can be held by a magnet, controlled by a timing device, with only the jaws within the heating loop. When sufficiently heated, the pliers are released to drop into the quench bath. Hedge clipper blades, located on a link chain circuit, progress the cutting edge only, through the 'U' shaped coil at controlled speed, to be followed instantly by a water-quenching spray. This latter system is utilized in the latest application, whereby rolls up to 30 in. dia. will be revolved whilst the coil traverses lengthwise, followed by the water spray. Heat penetration is here less critical.

These processes are quick, uniform and relatively scale free, indeed partial atmosphere control by a gaseous stream can be used if it is essential, but the installations are not cheap and are chiefly applicable to mass production methods. The advantages in rapid, scale-free heating with the consequent saving in time, reduced tool wear, and improved appearance when hardening finished articles, offset the current and installation charges, and increasing applications are being found economically advantageous.

Transfer by Conduction: In considering transferred heat, conduction is responsible for the even temperature distribution once the energy is within the stock. In properly designed furnaces, it plays little part for most applications, because the time factor involved is small if spaced loading is used and radiation and convective aspects are efficient. There are, however, two exceptions. Furnaces loaded with large pieces may of necessity have limited convective space between the pieces, and with considerable stock area hidden from direct radiation emitted by flames, brickwork or heating elements. In such cases the sheltered surfaces can only be heated by conduction.

Conduction time is also involved in the heating of large masses such as heavy ingots. Not only is the cross-sectional size involved, but it is difficult to provide even radiation and convective application, so that increased reliance has to be placed upon conduction. The temperature gradient through the metal causes stresses increased by metallurgical changes at certain ranges, reached successively from outside to centre, and if these forces exceed the critical limit, clinking will result. Recent investigations suggest that this factor, though important, has been exaggerated and that unnecessarily long and uneconomic heating schedules are common. Since mathematical calculations demanding simplifying assumptions are involved and the permissible stresses vary for different steels, it is not surprising that current practice is slow to incur what has seemed to be undue risk. In this field, the more widespread adoption of efficient methods is greatly to be desired.

cannot be so treated, for it would decompose with deposition of carbon, but since this fuel requires four to five times its volume of air for combustion, this in unimportant. The calorific value of gas is regulated by law, gas being sold by the therm of 100,000 B.Th.U., *i.e.* by heat content not volume. Though higher in initial unit cost than solid fuel, its flexibility, cleanliness and ease of control make it ubiquitous in a multitude of ferrous trades requiring heat. Low-temperature uses have forced circulation, and heat-treatment applications can employ a wide variety of combustion conditions achieved by air regulation. These range from high-intensity surface-combustion burners relying on radiation from a limited area, with consequent oxidizing conditions, to slow semi-luminous blanket flames which compensate in the area-radiation factor for what they lack in maximum flame temperature and intensity.

Cost prohibits town's gas for very large high-temperature furnaces, but the tunnel burner, recently further developed, is now claimed to achieve a heat release up to 250 million B.Th.U./cu. ft./h., and finds application for rapid heating external to furnaces, though assisted by refractory shapes. Less intense burners suffice for rapid heating to forging temperatures in smaller furnaces, and these applications make use of convection to a high degree.

The typical heat-treatment furnace may use neat gas to entrain its own primary air, recuperated secondary air being added at a later stage, or another type of burner employs low-pressure air from a fan about 20 in. w.g., to induce the gas from mains at 4 to 5 in. w.g. A variable mixture is provided which, once set, is constant over the supply range. Premixed gas and air under low pressure is sometimes used. The flame passes beneath the floor which contains the recuperation air flues, and emerges at the sides and/or towards the roof in under- and over-fired types, while another system uses side injected gas streams which mingle with preheated secondary air emerging from numerous roof apertures, producing a blanket flame. Balanced or even reducing conditions can be readily achieved by gas.

Electric-resistance Heating

Electric furnaces have developed in recent years and are of growing importance, despite the high cost of the initial energy. However, the heat conversion in the furnace approaches 100%, losses being due only to wall radiation, open doors and shutdown factors. There are no chimneys, flues, ports, burners, recuperators, etc., and especially no flue-gas losses. Radiation heat transfer is somewhat limited, since the resistance elements had a temperature limit of 1,150°C. recently extended to about 1,230°C. for continuous use. Compensation results from distributing the elements on walls, roof, floor and door, so that heating can be rapid and even.

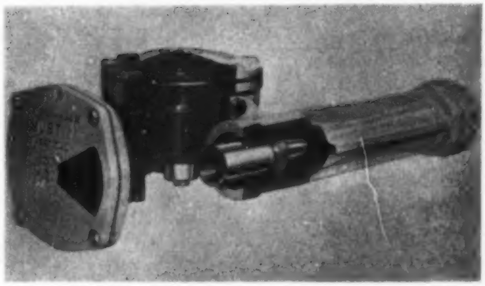

Fig. 3.—Automatic gas mixture controller to serve an air blast burner. Manufactured by Keith Blackman Ltd.

Automatic control may be simply incorporated and only electric furnaces can perform programme heating cycles by time switches, etc., without an attendant. The possibilities for weekend saving of labour are great, and general upkeep is low.

Resistance heating has not hitherto found application at forging temperatures, but a recent development provides ceramic elements capable of continuous use above 1,500°C. and experimental application to small forge furnaces is now proceeding. They should be effective if the cost is not prohibitive.

Uses of Fuel Oil

Fuel oil, though not 'on tap' like gas, is easily stored and distributed, and its estimated consumption may double within the next decade, subject to availability. Tar distillates having similar characteristics are used in three similar grades. The heaviest, requiring heated tanks and distribution mains is, with some exceptions, confined to large-scale melting, etc., and the types mainly used are the medium viscosity 200 sec. oil and the lighter diesel type fuel. By gravity feed or ring main, the oil is fed to the burners, before which in the former case pre-heating up to 140/180°F. is employed. Fuel oil should always be filtered and metered with bypass facilities.

Properly used, the characteristics are extremely high flame temperature and emissivity, so that heat transfer can be very good indeed. It follows that care must be taken to avoid flame inpingement on stock or refractories. There are two essentials, good atomization and correct oil/fuel ratio. The range of atomization has been quoted as between 10 and 200 μ ($1\mu = 1/1{,}000$ mm.), a good burner producing 85% atomization below 50 μ. If this is effected, satisfactory combustion can be achieved

incandescence thereby, radiate over a wide range of wavelengths as would a solid body, but in proportion to temperature and amount. Amount here means extent, volume and carbon particle concentration, *i.e.* luminosity; in a word, the 'solidity.' It is clearly important to secure the minimum of nitrogen and unburnt oxygen by efficient combustion, *i.e.* by reducing excess air to the lowest practical degree. This will secure the maximum gaseous radiation whether within the flame, luminous or not, or between the flame and exit port.

Fuels: Solid and Pulverized Solid

Solid fuel is now little used for direct heating. It is difficult to control automatically when used in large lumps, but smaller sizes have been successfully fed by an archimedean screw from hopper to grate bottom, using a variable feed. All the useful by-products extracted in the modern gas works are thus lost.

Pulverized solid fuel enjoyed a great vogue and is still used extensively. In ball or peg mill, coal up to ½ in., or, in special machines, up to 2 in., is crushed so that no more than 15% would remain on a 200-mesh sieve. The size governs the flame character, *i.e.* whether short and intense or long and lazy. Inherent moisture up to 10% can be dealt with, but surface moisture clogs the machines, so that fuel has either to be dried or delivered in sheeted trucks. It tends to be a dirty fuel in handling, and demands coal having a volatile content of not less than 20% for best results.

The flame is hot and of good emissivity, but there are two great objections. It is difficult to control by automatic means as regards temperature, and especially in relation to air/fuel ratio, and the fine ash particles provide a health problem if they are swept to atmosphere, or a practical difficulty if they are precipitated by a cyclone or allowed to clog long flues. There is the further difficulty that the fluxing action demands the resistance of dense, high alumina refractories, inefficient from the modern concept of thermal-storage and low-conductivity aspects. Even then, furnaces so fired are frequently filled at hearth level with liquid slag only partially removable (with heat loss) when molten, and disposed of with an expenditure of time and cost when cold.

Producer Gas

Gaseous fuel is a medium of wide variety in application. Until recent times, heavy industry to a large extent utilized the gas producer for steel heating. The principle was to use a small and controlled proportion of the combustion potential external to the furnace and this heat drove off the tar and volatile constituents from the bulk of the sized coal. If the steam-induced air blast were at the optimum saturation, as indicated by the temperature, and the fuel bed conditions and thickness satisfactory, then the carbon dioxide produced, together with the water vapour, would react with the heated coal or coke to form the combustible gases, hydrogen and carbon monoxide.

Such a gas, though bland and voluminous, has a low thermal value approximately 150 B.Th.U./cu. ft. This is due to the high and unavoidable gas content of inert nitrogen and residual carbon dioxide. When using fuel having a volatile content between 20 and 40%, the B.Th.U. value of the gas is increased by 15/cu. ft., due to entrained tarry products and slightly more by the sensible heat in the gas, which must be used close to the producer to avoid the deposition of tar, soot, etc. For these reasons, the flame temperature, and therefore the heat transfer coefficient, is low. It is assisted somewhat since the theoretical air requirement is little more than the gas volume, and this implies considerable preheat from the brick recuperators usually employed, with a consequent increase in flame temperature and economy. A reasonable composition would be CO_2, 6%; Co, 25%; H_2, 13%; and hydrocarbons, 3·5%.

A similar process uses non-bituminous fuel, coke or anthracite—clean gas, scrubbed and having the sulphur removed, being the product. This can be piped some distance, but the sensible heat and that due to tarry products is lost, as well as the extra radiant power due to luminosity. It does, however, lend itself to more precise application in smaller burners having direct control.

It seems undesirable that the most scarce and expensive fuel, anthracite, should be so used, or that all the valuable by-products extracted in a modern gas works should be lost when using bituminous fuel in a crude-gas producer. Coke is not bituminous and does not have these objections.

Modern units contrive furnace control at the producer, having automatic fuel feeding as well as distribution and mechanical ash removal regulated from the recording of blast temperature, gas temperature and pressure, air volume, etc.

A clean gas plant is sometimes used for a battery of smaller type furnaces, but suffers from a lack of flexibility, since the labour and overhead charges are almost constant and the efficiency decreases at low loads.

Producer gas is used for forging and heat-treatment temperatures.

Town's Gas

Much higher calorific value, up to 500 B.Th.U./cu. ft., can be obtained from town's gas, and in consequence the theoretical flame temperature may be as high as 2,000°C.—if the air is preheated this figure may be further increased. The gas itself

(and heat) diminish and the carbon dioxide and water vapour figures increase with a consequent improvement in the gaseous radiation. Finally, shorter flames, if otherwise tolerable, increase the flame to port distance and give a fractional gain in the gas radiation time, and there is reduced tendency for unburnt combustibles to escape. These additive factors are usually under-estimated, and sometimes ignored, yet with large units there are underlying implications as to output in restricted space, spread of overhead costs, etc.

Oil fuel is most suitable for high-temperature work, or otherwise by air circulation separately heated from the furnace chamber. It has been directly applied for heat-treatment ranges, but adequate diffusion of heat from such an intense source provides a problem. Honeycomb roofs generally used below the combustion space, detract from the efficiency of direct radiation.

Fuel oil, common for melting or limited size reheating, is less easy to apply to large masses. The high temperature reached and radiation released in a short flame length, creates differences around the section, quite apart from the gradient through it. The shape of slab or ingot baulks re-radiation beneath, and that from convected combustion products is inadequate for even heating. Extra time is expensive. If resource is made to the disposition of numerous smaller burners to overcome this, a problem is created in siting exhaust ports to avoid short circuiting. Moreover, by the Lambert cosine law for radiation, efficiency requires that the maximum area of flame be presented to the steel rather than the tip. This is a further difficulty.

A new process may offer a solution. The gasification of fuel oil can be accomplished externally, controlled as to quantity and flame character, *i.e.* air/oil ratio, and retaining 95% of the original potential, either as latent or sensible heat. The flame is both luminous and voluminous with a greater spread of heat release. Many such plants are found on the Continent, and several are being installed in Great Britain.

Furnace Instrumentation

Instrumentation has to be considered when discussing the effective application of heat. Simple high/low temperature control apparatus can be obtained for a little over £50, and yet large furnaces are found operating without so much as an indicator. Controlling recorders of more elaborate type are often essential and a furnace pressure gauge is useful for damper setting. Pressure control is now more frequent for large units, whereby the infiltration of cold air is prevented and efficient combustion secured with a minimum of excess air. The temperature of recuperated air should be checked and the carbon dioxide content of flue gases known, either by simple portable apparatus or even as Orsat gas analyser. Large furnaces would justify a continuous CO_2 recorder so that conditions throughout a heat could be ascertained.

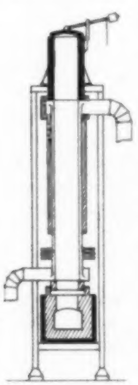

Fig. 7.—Metallic recuperator for furnace gases up to 1,400°C. and air-preheat to 700°C. (Stein & Atkinson Ltd.)

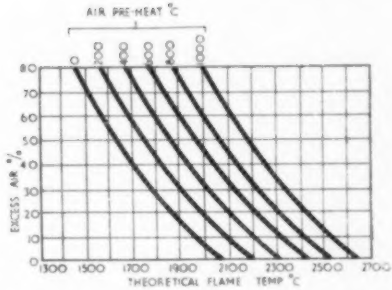

Fig. 8.—Approximate effect of excess air and preheating of combustion air on theoretical flame temperature. ('Fuel Oil in Furnaces.')

Refractories and Insulation

Furnace refractories are an important aspect of effective heating. Modern cements, having a high cold-strength, reduce the incidence of brickwork cracks and so minimize the infiltration of cold air. Refractory wash coatings for brickwork not only protect the surface, but can increase the reflective factor and so assist re-radiation, while reducing wall losses. Hot-face insulation bricks are still insufficiently used in connection with gas and oil. It is true that floors, jambs and parts liable to mechanical damage or to molten scale or slag contact are not suited to this kind of construction, neither are they suitable for pulverized fuel or crude gas firing. For many applications, however, the roof and wall losses can be much reduced by the use of hot-face insulation. Moreover, by reason of their low bulk density, the thermal storage capacity of these bricks is limited; this, together with the permissible reduction in wall thickness, results in rapid furnace heating, the greatest economy being obtained with intermittent use.

As yet, little use is made of fibre insulating materials, such as Therbloc for outer linings. Light, easily applied, reasonably cheap, accommodating expansion and distortion, it yet possesses within its temperature limit of 800°C., far better

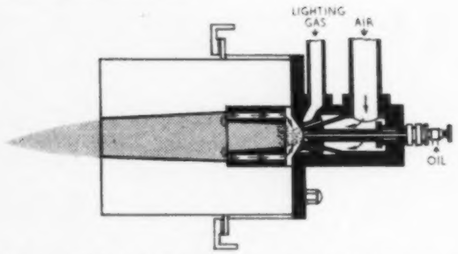

Fig. 4.—High-intensity oil burner for light oil or town's gas. Made by David Etchells & Son Ltd.

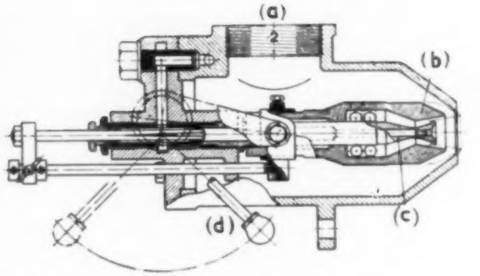

Fig. 5.—Constant air/oil ratio burner for low-pressure air and 200-sec. fuel oil. (Schieldrop & Co. Ltd.)

with only 10 to 20% excess air over the stoichiometric amount. Excess air, all too frequently, results in considerable oxidation and a heat flue loss more than 60% of the total input, so that induced secondary air around the burner quarl should be avoided.

Three of the many types of burner may be noted. The first uses light diesel oil, a little more expensive but having a slightly higher calorific value, which does not require pre-heating and can be proportionately mixed and atomized from a float chamber by varying the amount of a low-pressure air supply. The air/oil ratio can be set, then remaining constant at varying loads. Hot gases issue into a short double-walled refractory tube, a small proportion being sucked back down the annulus to provide atomizing heat and increase turbulence. Combustion is almost complete within the tube so that the very hot gases emerge at high speed, making the burner very suitable for smaller furnaces by retaining a convective factor. For the normal fuel oil, self-proportioning burners are available, again using low-pressure fan air at about 20 in. w.g. Hitherto, the difficulty has been that to employ a turn-down ratio of 4 to 1 the reduced but proportionate air supply would fail to atomize correctly by reason of diminished air pressure, or else, if this be retained, wasteful excessive air would remain. In later designs, a varying annulus, where the air emerges, retains constant pressure while varying the amount, and air/oil ratio, once set, remains fixed at varying loads altered by a single lever and suitable, as in the previous example, for simple automatic control. Low pressure burners cannot accommodate highly preheated air, since the total quantity passes through the burner and would crack the oil, clogging the burner. Also, the expansion of air with temperature rise alters the ratio between oil and air, and destroys the control principle. Such burners are chiefly used in smaller furnaces where recuperation saving is small in comparison with that effected by control of combustion conditions, in conjunction with furnace design and materials.

For larger furnaces, recuperation or regeneration is essential for efficient operation and 15 to 20% saving in fuel cost alone may be made.

Medium pressure burners are employed where a small fraction of cold air at 10/14 lb./sq. in. is used for atomization, constant at all loads. The preheated secondary air from a low-pressure fan, and as hot as possible, is fed in proportion to the oil around the primary stream, but does not pass through the burner. A sizable installation is required to justify the complication of a dual air supply from a rotary compressor and low-pressure fan.

When preheated air, perhaps exceeding 500°C., is used, the advantages are cumulative and extend far beyond the return of a useful fraction of the waste-gas heat to the furnace. The flame temperature is increased beyond that otherwise obtainable; heat transfer is faster and the time factor reduced. There is a consequent saving in flue gas and external radiation heat losses. Moreover, chemical reactions vary in intensity with temperature, so that complete combustion can be secured in a shorter time and with less excess air. Again, flame temperature tends to rise, the waste gas volume

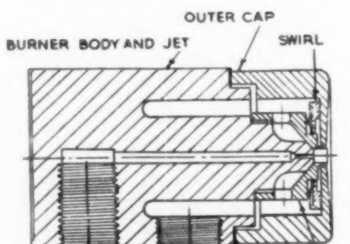

Fig. 6.—Medium-pressure oil burner for either 200- or 950-sec. oil and atomizing pressure of 10 to 14 lb./sq. in. Low-pressure recuperated secondary air up to 700°C. does not pass through burner. ('Fuel Oil in Furnaces' by M. Roddan.)

designs are prepared and some furnaces are constructed by the user.

Furnace efficiency is not precisely definable. The figure obtained, as a percentage of the calculated heat input related to that usefully found in the product, may differ considerably between a test heat and operational practice. Small successive delays, time between shifts, the number of door lifts per heat, etc., all reduce the figure for the workshop floor. Light stock or under-charging tend to a similar result. Up to 20% efficiency is possible for fuel fired, batch-type furnaces; 12 to 15% may often be achieved; 5% or less is all too common.

Where crude producer gas of varying calorific value is flowing at different rates, or if partially forged ingots are re-charged, still hot, for a portion only, assessment is difficult owing to conduction losses. For such cases, judgment must depend upon known furnace conditions, *i.e.* the unit rate rather than the total amount of wall and roof losses, the CO_2 content of flue gases, the furnace pressure and recuperator temperature, etc. Programme control can secure a desired heating rate and, within the furnace capacity, readiness at an opportune time, but without undue soaking.

The total heat of steel varies with composition, and it is possible that published figures may vary within 20%.[2, 3] Efficiency is so low that even such an error in basic data makes little difference to the final figure, especially for workshop comparison.

In general, metallurgical aspects of heating cause less difficulty than is supposed. For heat treatment, oxidation and decarburization are catered for by salt baths or controlled atmospheres. Without these, detached scale from machined surfaces may range from 0·004 to 0·007 in. thick. Occasional expedients used are charcoal, borax solutions or refractory cement coatings. Ceramic glazes are being developed. At forging temperatures, however, there is no doubt that an avoidable degree of oxidation is prevalent, with its implication of bad combustion conditions, waste of metal, poor surface finish and excessive wear of tools, dies, rolls, etc.

In one instance from medium size forgings of 5 to 10 cwt., the plates of primary detached scale ranged from 0·07 to 0·14 in. The extent of the variation indicates undue soaking or avoidable differences in combustion conditions. Overheating is common in those instances where a temperature head is maintained in the furnace to secure rapid heat transfer. The time rhythm is important, and if accidentally prolonged, even for a few minutes, excessive grain growth is caused. This is a matter of degree and, if moderate, subsequent hot working and deformation mitigate the results; if severe, permanent impairment of physical properties will occur. Above about 1,400°C., there is danger of

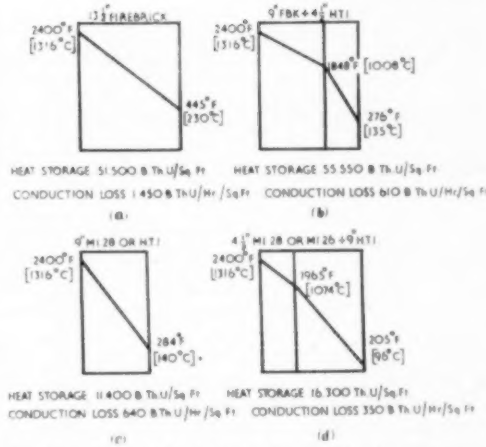

Fig. 11.—Effect of insulation on heat conduction and storage losses in furnace walls

the second or burning stage developing, in which oxidation proceeds beyond the surface and between the grain boundaries. This is serious and usually leads to rejection of the processed material.

Until comparatively recently, many special steels and large masses were heated at unduly slow rates. Work in Poland indicated that an 8-ton ingot could be raised to forging heat in 3½ hours.[4] BISRA investigation confirmed the principle for tool steel ingots of 10 in. square.[5] For example, EN.25 up to 14 in. square can safely be placed in a furnace at forging heat. The calculation of a safe limit for large ingots is an involved matter, for allowance must be made for residual stresses from the preceding cooling, and the composition will have some effect.[6] Various simplifying assumptions result in useful practical graphs.[7] In the U.S.A. 50-ton ingots of medium carbon steel have been heated for forging in 16 hours,[8] but British furnace equipment often sets a much slower rate.

The examination of any heating problem can only be summarized in general terms—equipment, fuel, combustion conditions, heat transfer, temperature and other control, insulation, recuperation, relative efficiency and overall unit cost.

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(8) J. Finkl, private communication.

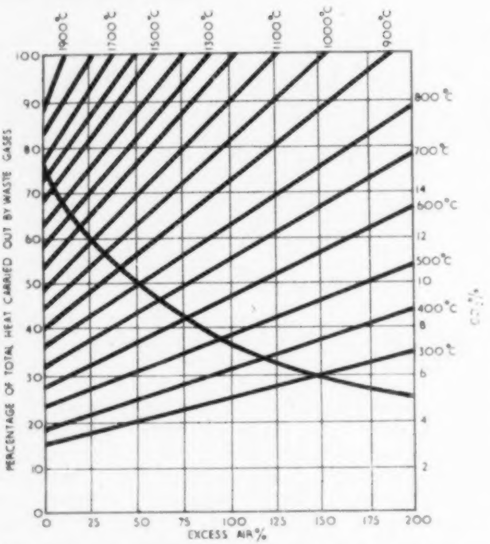


Fig. 9.—Effect of excess air on amount of heat carried out in waste gases. (*'Fuel Oil in Furnaces'*)

low-thermal conductivity than any refractory material.

Metal sheeting coated with high-temperature aluminium paint reduces both air infiltration and external heat losses, because the heat emissivity of this surface is relatively low.

Furnace Design and Maintenance

Furnace design is so vast a subject that only brief mention can be made of its significance in efficient heating, irrespective of the fuel used. Continuous furnaces, straight, or revolving and circular, may give up to 40% efficiency. This is due to the counterflow principle, whereby combustion products yield useful heat to the cooler stock as it advances. Where applicable, double ended furnaces sometimes bring a worth-while economy. For forging purposes, firing from either side enables heat to be saved and extracted in the alternate preheating chambers. In heat-treatment practice, double-bogie furnaces often permit the thermal storage cost to be carried over successive heats until the weekend shutdown. The same advantages, together with flexibility as to charge unit size or type, may be secured by a battery of furnaces served by a charging machine. It is for this reason, and for the furnace time involved, that normalizing is to be preferred to annealing where suitable.

Furnace maintenance is an important consideration, and doors should be light, well-fitting, and except for smaller items, mechanically operated. In a certain size range, removable roofs are the key to skilful repair without exhaustion; in large units they should be separately supported to allow bonded wall replacements.

Many furnaces, mainly for heat treatment, are available in various sizes, and prospective buyers should be aware of the factors involved. There is a reasonable range loading within which heating is satisfactory. Above or below this, the unit cost increases rapidly, therefore the heating capacity should match the forming operation, or heat-treatment throughput. For larger sizes, individual

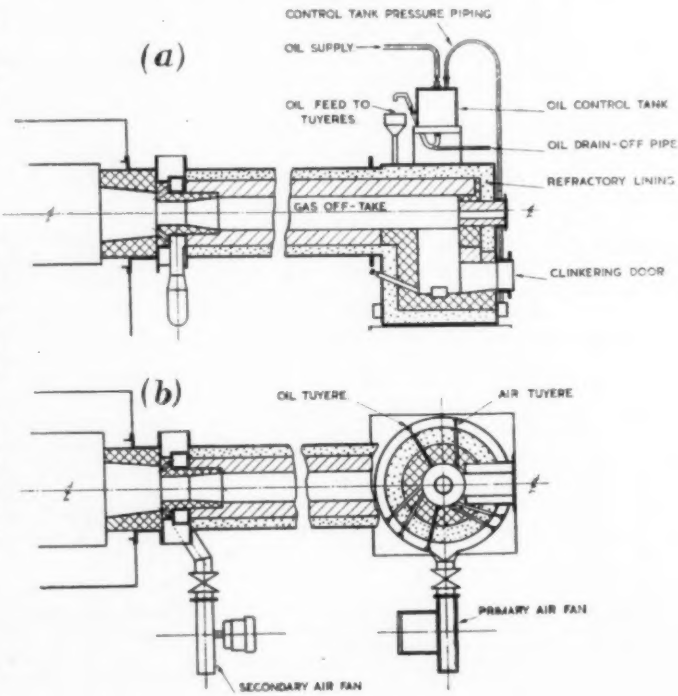
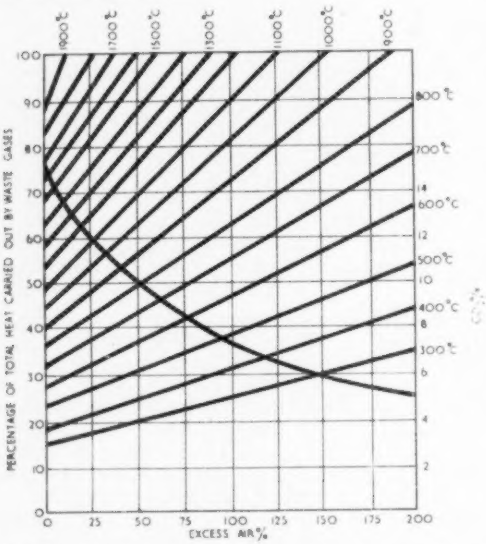


Fig. 10.—(a) Vertical section, (b) plan section through centre line of gas main to furnace of oil cracker gasifier for heavy fuel oil. (*Wellman Smith Owen Engineering Corp. Ltd.*)



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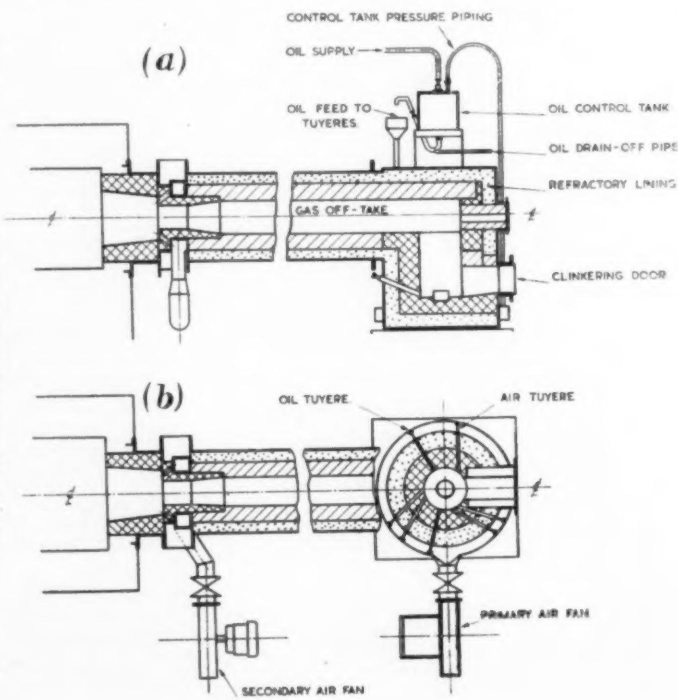

Fig. 10.—(a) Vertical section, (b) plan section through centre line of gas main to furnace of oil cracker gasifier for heavy fuel oil. (Wellman Smith Owen Engineering Corp. Ltd.)

designs are prepared and some furnaces are constructed by the user.

Furnace efficiency is not precisely definable. The figure obtained, as a percentage of the calculated heat input related to that usefully found in the product, may differ considerably between a test heat and operational practice. Small successive delays, time between shifts, the number of door lifts per heat, etc., all reduce the figure for the workshop floor. Light stock or under-charging tend to a similar result. Up to 20% efficiency is possible for fuel fired, batch-type furnaces; 12 to 15% may often be achieved; 5% or less is all too common.

Where crude producer gas of varying calorific value is flowing at different rates, or if partially forged ingots are re-charged, still hot, for a portion only, assessment is difficult owing to conduction losses. For such cases, judgment must depend upon known furnace conditions, *i.e.* the unit rate rather than the total amount of wall and roof losses, the CO_2 content of flue gases, the furnace pressure and recuperator temperature, etc. Programme control can secure a desired heating rate and, within the furnace capacity, readiness at an opportune time, but without undue soaking.

The total heat of steel varies with composition, and it is possible that published figures may vary within 20%.[2, 3] Efficiency is so low that even such an error in basic data makes little difference to the final figure, especially for workshop comparison.

In general, metallurgical aspects of heating cause less difficulty than is supposed. For heat treatment, oxidation and decarburization are catered for by salt baths or controlled atmospheres. Without these, detached scale from machined surfaces may range from 0·004 to 0·007 in. thick. Occasional expedients used are charcoal, borax solutions or refractory cement coatings. Ceramic glazes are being developed. At forging temperatures, however, there is no doubt that an avoidable degree of oxidation is prevalent, with its implication of bad combustion conditions, waste of metal, poor surface finish and excessive wear of tools, dies, rolls, etc.

In one instance from medium size forgings of 5 to 10 cwt., the plates of primary detached scale ranged from 0·07 to 0·14 in. The extent of the variation indicates undue soaking or avoidable differences in combustion conditions. Overheating is common in those instances where a temperature head is maintained in the furnace to secure rapid heat transfer. The time rhythm is important, and if accidentally prolonged, even for a few minutes, excessive grain growth is caused. This is a matter of degree and, if moderate, subsequent hot working and deformation mitigate the results; if severe, permanent impairment of physical properties will occur. Above about 1,400°C., there is danger of

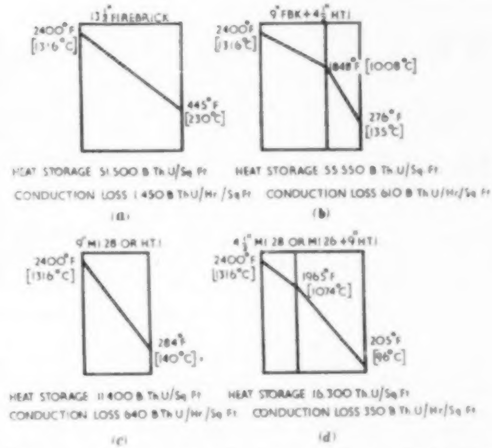

Fig. 11.—Effect of insulation on heat conduction and storage losses in furnace walls

the second or burning stage developing, in which oxidation proceeds beyond the surface and between the grain boundaries. This is serious and usually leads to rejection of the processed material.

Until comparatively recently, many special steels and large masses were heated at unduly slow rates. Work in Poland indicated that an 8-ton ingot could be raised to forging heat in 3½ hours.[4] BISRA investigation confirmed the principle for tool steel ingots of 10 in. square.[5] For example, EN.25 up to 14 in. square can safely be placed in a furnace at forging heat. The calculation of a safe limit for large ingots is an involved matter, for allowance must be made for residual stresses from the preceding cooling, and the composition will have some effect.[6] Various simplifying assumptions result in useful practical graphs.[7] In the U.S.A. 50-ton ingots of medium carbon steel have been heated for forging in 16 hours,[8] but British furnace equipment often sets a much slower rate.

The examination of any heating problem can only be summarized in general terms—equipment, fuel, combustion conditions, heat transfer, temperature and other control, insulation, recuperation, relative efficiency and overall unit cost.

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The Technique of Forging

An Annual Review

PROF. DR. ING. O. KIENZLE, AND DR. ING. K. LANGE

In this paper, presented at the Verein Deutscher Ingenieure last August, the authors review the published literature on forging which appeared in 1956. Prof. Kienzle is principal, and Dr. Lange is investigator, at the school of forging technology attached to the Technische Hochschule, Hanover, Germany

SIMILARLY as in the reviews for previous years we have to report several papers concerned with the technique of forging or deal with the methods of predetermining the force and the energy required in forging, and the efficiency of this process. E. Siebel in his contribution gave a review of the present state of scientific knowledge in hot working.[1] A. Geleji has developed a new method of calculating the forging force and the work required in drop forging;[2] the usefulness of this method is yet to be confirmed in practical works applications. Reicherter was concerned with the influence of friction on the deformation forces required in drop forging of turbine blades.[3] Lueg, Fink and Müller have extended the limits of our knowledge with regards to the influence of the degree and rate of deformation on the resistance to deformation; they were first to establish a relationship between these variables.[4]

A contribution on the same subject has been made by Henkel[5] in his work on the behaviour of commercial steels during dynamic upsetting at elevated temperatures; he also established a relationship between the velocity of and the resistance to deformation. Further developments in this field are expected in the near future. All these contributions provide more accurate data relating to the deformation process and will therefore facilitate the calculation of forces and energies required in forging.

Press and Hammer Forging (Without Dies)

In view of rapid technical development and progress, it appears to be advantageous to prepare separate reviews for individual branches of forging, giving details of technical background, possibilities and limitations of the process, installation and design of modern large forges, use of ingots and semi-products as the metal stock, etc.[6]

The choice of material is a governing factor, particularly in the case of large forgings, and must be given attention already at the melting stage. Eminger and Kinsky[7] discussed the respective advantages of using acid and basic steels for large forgings (crankshafts). The manufacturing cost of acid steel is considerably higher, but its use helps to reduce scrap figures, and therefore in some cases it pays to employ this material.

The advantages of vacuum de-gassing of steel have been discussed by A. Tix.[8] The vacuum pouring of large forging ingots weighing up to 150 t. (metric) reduces the hydrogen content to such a low level that susceptibility to flake formation is completely eliminated. Additional advantages of this process include a lowering of the oxygen and nitrogen contents, a reduction of gas porosity and an improvement of quality. All these factors help to ensure higher output, particularly in the production of large rotors for steam and gas turbines.

The attainment of certain predetermined properties in the material after forging is considered to be of great importance; for example, it might be desirable to ensure a uniformly soft annealed structure in order to facilitate machining, or a high degree of toughness in the centre of heavy components might be required. A complete uniformity of the annealed structure can be secured if immediately after the hot-forming operation the steel is first allowed to cool to a temperature between Ac_1 and Ac_3, and then transferred to a furnace preheated to this temperature and cooled slowly to 600°C. approx. in about 7 h.[9]

A high degree of toughness can be induced in carbon and low-alloy steel forgings (with the fixed maximum amounts of alloying elements) by a suitable heat treatment even in the absence of the elements promoting deep hardening characteristics. The treatment consists of heating to a temperature above Ac_3 and quenching, then reheating to a temperature between Ac_1 and Ac_3 and requenching, followed by a normal tempering.[10]

Further development of forging presses is an important necessity for the economics of the forging

trade. Elkan and Lewis provided a review of the recent development in this field, particularly in the control technique; among other things, they discussed efficiency and equipment of modern presses, driving mechanisms, hydraulics and construction.[11] A contribution relating to the design of hydraulic systems has been provided by Brill in his research on the fluctuation of pressure in the high-pressure circuits of hydraulic presses.[12] According to this work the hydraulic fluctuation can considerably be reduced by a volume shock absorber at the position of origin and a throttle diaphragm at the position of reflection of the pressure thrust.

Similarly as in any other plant employing high temperatures, the economic utilization of the heat energy in the forging furnaces is of primary importance. Continuous attention is therefore given to the need for further developments in this field. In the last few years there has been a rapid expansion in the use of oil-fired furnaces, and practical operational data are still coming in.

Neumann and Seitz[13] have made a contribution on this subject by investigating the operation under production conditions of a gravity-discharge furnace for billets equipped with an atomizing oil-burner. The known difficulties with the atomization of oil are responsible for troubles such as suction of air from outside, increased scaling or carburization of the charge. It is, however, possible to eliminate these difficulties to a large extent by modifications to the furnace design, and by controlling the atomization of oil. Finally the problem of furnace-pressure control has been dealt with in a paper by Jeschar.[14]

Drop Forging (Use of Dies)

Drop forging, as a process of mass production, has, of course, different problems than those encountered in the individual production of large forgings. Tools and machines as means of production are in this instance of considerably greater significance; the same applies to the heating and the drop-forging method employed. The economic significance of these factors was outlined in the lectures given at the International Drop-forging Congress in Düsseldorf, Hanover and Baden Baden in 1956.[15, 16, 17]

At this congress, which in future is to be held once every three years in a different country, several points were made concerning international co-operation in solving technical problems. As a contribution towards better understanding, a German-English-French technical dictionary covering the field of drop forging[18] was published. The historical development of drop forging was outlined by H. Kaessberg;[19] A Siepmann surveyed a few 'trouble spots' in the drop-forging industry: supply of material and energy, development of automation, and conservation of the human element.[20]

As the cost of materials constitutes a high proportion of the cost in a drop-forging plant,[21] it is absolutely necessary to use materials in an economical manner. A number of interesting points on this subject can be found in a book by Malikow which is available in German translation.[22]

The importance of economical furnaces, which would also ensure uniform heating with little scaling, has been pointed out in a number of papers. The increasing use of oil fuels results in a number of problems requiring development work; furthermore, the problem of control of even small forging furnaces has acquired great importance.[23, 24, 25] The change-over from gravity-discharge furnaces into the furnaces operating in rhythmical cycles—assuming that the production remains unchanged—has created the basis for continuous production line. Induction heating must also be assessed in a similar manner; the dependence of the forging on the heating rhythm governs the entire production cycle.[26]

Attempts to standardize machines used in hot forming have in most cases been successful, but the relevant standard specifications have not yet been published. The following specifications are now practically ready: Mechanical presses including trimming presses;[27] belt hammers and board hammers.[28, 29] For the belt hammers, which in the Federal German Republic are the most frequently used drop-forging machines, it was possible to develop a control mechanism controlled by the operator's foot and actuated by compressed air.[30]

Callaghan surveyed the development of drop-forging machines from the British point of view.[31] Evans discussed the use of heated compressed air in forge hammers, and it should be mentioned here that this technique has been finding increasing application in recent years in Germany.[32] In connection with the general tendency towards mechanization in all instances where there were favourable conditions, the horizontal upsetting machines were the first to be employed for continuous production cycles in the manufacture of valve tappets.[33]

Drop-forging Dies

The production costs of drop-forging dies have a very pronounced influence on the price of the forgings themselves. In recent years new die materials have been developed and old ones improved. A comprehensive review of the possibilities in the field of die manufacture has been given by Kienzle.[34] Individual production methods such as conventional machining or spark erosion have been described in a number of papers.[35, 36, 37] Practical aspects of die-making are also covered by two VDI instruction sheets—one of them being

concerned with die-sinking by cold hobbing,[38] the other with inserting and uses of drop-forging dies.[39]

The preparation of the standard specification covering milling cutters for dies is now completed,[40] and has already resulted in a better adoption of cutters for various tasks; its publication is to be expected shortly. The maintenance of close dimensional tolerances in the production of dies helps to keep to a minimum their wear, *i.e.* to extend their service lives. According to Kienzle, Lange, Meinert and Arend these conditions can be achieved by a suitable surface treatment, among others, by hard chromium plating.[41, 42] A 'VDI' instruction sheet on surface treatment is also available for the use in works.[43] It should also be mentioned that the proper die lubrication is of great importance.[44]

The fastening of forging tools on hammers and presses has been dealt with by Storer and Tolkien. On the basis of numerous practical data, these workers put forward suggestions regarding internal works standardization of the dimensions of die joints and die shanks. The standardization of the dimensions of die shanks may result in a considerable saving of time if the machining of dies is carried out externally.[45]

Generally speaking, drop forgings are rough blanks, and in most cases they are subjected to a machining operation. In order to ensure the highest economy, *i.e.* the lowest total cost of the finished component, the forgings must be so shaped as to facilitate the machining. On the other hand, by a suitable arrangement of the handling and cutting equipment in the machine shop it is possible to improve the profitability of drop forging still further. These problems are discussed by Lange and Kemna.[46]

An extensive discussion of the development problems in the drop-forging technique has been presented by Niederhoff and Schieferdecker.[47] They have shown methods of improvements in drop-forging process by means of mechanization. The difficulties which are due to the process itself —the high temperatures involved having a very important influence—are so big that automation is possible in a few individual cases only and, furthermore, requires new specially designed machines. An extensive mechanization is, however, necessary if the drop-forging industry is to retain its status in the future industrial development.

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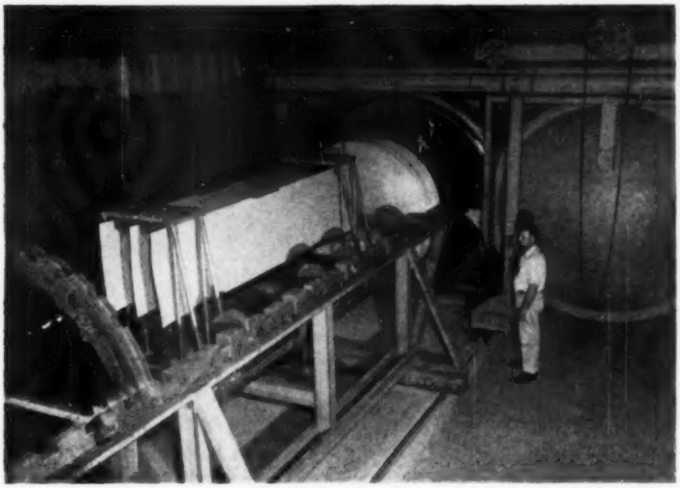
Ceramic Tool Research

PERFORMANCES of six types of ceramic tool are being investigated at the Melton Mowbray headquarters of the Production Engineering Research Association on behalf of the Ministry of Supply. For comparison purposes, similar tests are being carried out on cemented carbide tools.

The performance of the tools will be determined over a range of cutting speeds and feeds, both when rough- and finish-machining alloy steel. Performance will be assessed on the basis of tool wear in roughing operations and of workpiece surface finish in finishing operations. The machining experiments will be performed on a 17-in. swing high-speed centre lathe with built-in running centre and variable speed range. Vibration has a particularly destructive effect on the performance of ceramic tools and special attention is being given to the vibration characteristics of the machine tool.

An examination will also be made of some economic aspects of the use of ceramic tools by carrying out tests in which the effects of various feed and speed combinations giving constant rates of metal removal will be explored. These tests will indicate the most suitable combinations of feed and speed for specified rates of production.

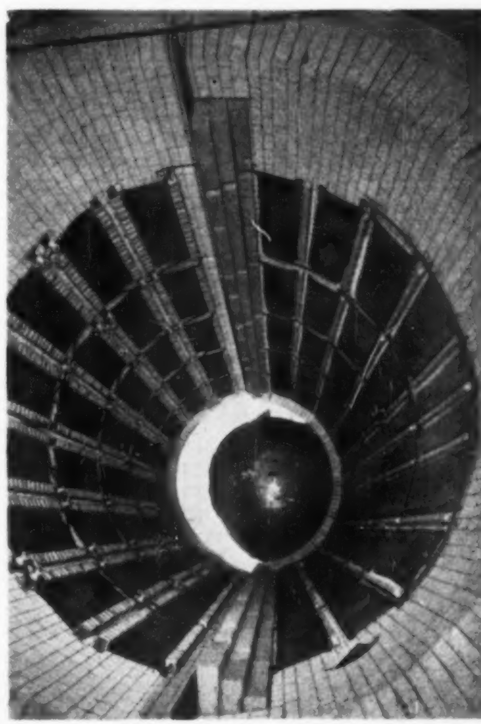
VACUUM FURNACE FOR TREATING TITANIUM



New American Installation

Titanium sheets being conveyed into the vacuum furnace

Below, the electric heating elements which produce temperatures up to 2,100°F.



PROBLEMS associated with the production, brazing, heat treating, annealing, and stress relieving of titanium are currently being solved with a large vacuum furnace recently made by Lindbergh Engineering Co., Chicago, for North American Aviation Inc., Downey, California.

In addition, the furnace can be satisfactorily used to process zirconium for nuclear reactors and other metals requiring complete protection against oxidation at elevated temperatures.

The practicality of many unusual features in the design of the unit was established some time ago by laboratory and pilot furnaces, both of which are still used in the Downey plant. In fact, the pilot installation is said to have paid for the production furnace by allowing the company to salvage over $2 million worth of titanium scrap.

Because it is more than 40 ft. long and has an inside diameter of 78 in., the new vacuum furnace can handle flat 4 ft. by 12 ft. sheets and is believed to be the largest facility of its type in the world today.

Some Features of the New Furnace

The furnace has two internal zones. One produces temperatures up to 2,150°F., and the other has water cooling tubes which can reduce parts temperatures so rapidly that a heat-treated load may be removed from the furnace only 30 min. after the end of a processing cycle. Alternate heating and cooling in adjacent furnace zones is made

Heat Treating Aluminium Alloys

Outline of Theory and Practice

AN exceedingly complex structure is possessed by certain combinations of metals like those found in the aluminium alloys. Thus a molten aluminium alloy, states G. W. Birdsall,[1] Reynolds Metals Co., Louisville, Kentucky, may be composed of six to nine different metals, some dissolved in others, like ink in water, others not dissolved but just mixed in like oil in water. As the molten alloy is allowed to cool, it will reach a point where solidification begins. At this point, crystals begin to form, and continued cooling, additional crystals building up on the first ones, in turn producing grains. Now the solidified metal is composed of grains, in turn composed of crystals.

In addition, certain compounds are formed by the various combinations of metals. These may solidify out separately, either between the grains along the grain boundaries, or in the grains between the crystals.

Time Element in Metal Treating

Most changes in the structure of a metal require a certain amount of time for completion, and it is important to understand the influence of time in heat treating metals. Also time is required for the heat to soak thoroughly throughout all portions of the metal piece being treated, so that sufficient temperature rise be produced in all sections to provide the desired change in metallurgical structure. Allowance for proper time 'at temperature' is essential in any heat treatment.

The time element enters into heat treatment in another important manner. Because a certain period of time is required for structural or metallurgical changes to reach stability, it is possible to change the temperature of the metal rapidly and thereby obtain at room temperature certain desired types of structures not otherwise obtainable.

As a pure metal is allowed to cool from the molten state, a temperature is reached where it begins to solidify or freeze. For pure aluminium, this freezing point is 1,220·4°F. The temperature remains at this value for a period because the change from a liquid to a solid is accompanied by the release of heat, the mechanism of the operation being such that just enough heat is released to balance that being lost, thus retaining the temperature of the metal constant during the period this solidification is taking place. As soon as the metal has completely solidified, its temperature again falls gradually as it is allowed to cool.

The foregoing applies only to a pure metal. When two such metals, aluminium and copper for instance, are melted together and allowed to cool, there exists a combination which has a freezing 'range' instead of a freezing 'point'; that is, the material begins to freeze at one temperature and continues to freeze while the temperature falls to a lower value before all of it has solidified. The combination of aluminium and copper does not freeze or solidify completely at a single temperature because the mixture formed by the two metals behaves in an entirely different manner than pure metals like copper or aluminium alone.

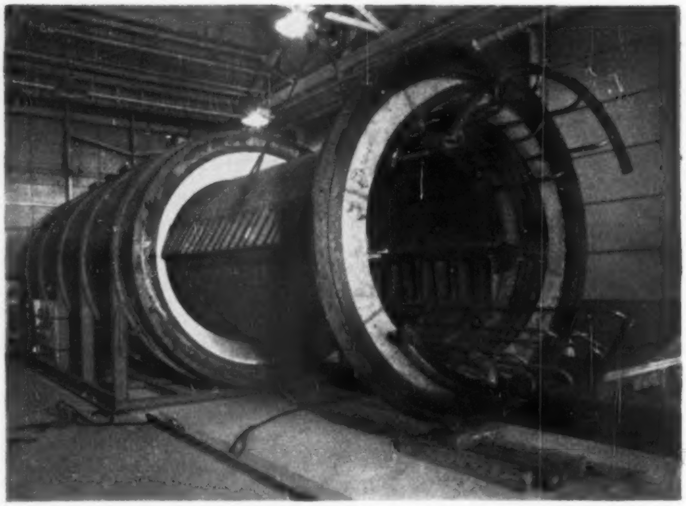
Differential Freezing and Precipitation

The crystals forming out as the molten metal is just beginning to solidify will consist of an alloy of almost pure aluminium. As the temperature falls, crystals with appreciable amounts of copper will begin forming. With continued falling temperature, the crystals forming will contain more and more copper. Thus as the temperature falls, the material freezing out of solution at any particular moment corresponds to the alloy of aluminium and copper that freezes at that particular temperature. When the molten metal contains more than two elements, the freezing action becomes increasingly complicated. Thus it is evident that in an aluminium alloy where there may be from six to nine different elements, the action may be extremely complicated, because the many different elements in turn form various mixtures or compounds which may behave in still different ways to further complicate the situation.

One of the complications resulting from having numerous different elements in the aluminium alloy is that certain combinations of elements may form mixtures or compounds which may freeze out of solution or separate out in small independent particles before or even after more of the other material has solidified. These particles may be extremely small and may exist between the surfaces of adjoining crystals in such a manner as to lock the crystals by hindering them from sliding and thus increasing the resistance to mechanically working the material. This in turn may make the metal hard, tough, brittle, etc., the result being desirable or undesirable according to circumstances.

Cooling and Solid Diffusion

When a molten aluminium alloy is allowed to cool, various elements and combinations of elements will precipitate out of the molten alloy as the temperature falls to a point where they can no



12,000-lb. Inconel retort or inner shell being inserted in the furnace

possible by a series of 14 vertically mounted radiation baffles, which separate the two areas and permit the concentration of heat from electrical elements where it will do the most good.

Other features include a retort or inner shell comprising about 12,000 lb. of Inconel; it is separated from the furnace's mild steel outer shell by a 14-in.-thick layer of fire and insulating brick.

The vacuum system can evacuate the furnace's 1,400 cu. ft. interior in 23 min., and maintain pressures as low as 0.3μ. This system includes three rough pumps, two 16-in. diffusion pumps, and one small holding pump.

The battery of three transformers for the three-zone control of Lindbergh rod-type heating elements require 820 kW. of power.

The caterpillar-type conveyor cart can handle a 1,000-lb. load of parts. Made from Inconel, this cart can be moved to or from hot and cold zones within the furnace by means of an electric motor, vacuum seal bearings, and external gears.

A standard high-pressure valve allows gas from an external container to enter the furnace, when an inert atmosphere is needed, and a sliding furnace door which can be sealed by means of a groove and ¾-in. O-ring by means of a chain and Acme-thread mechanism is incorporated.

Furnace Applications

Titanium materials being heated in the furnace include 6A1-4V, RCA 110AT, 8 Mn, and bar stock alloys as well as commercially-pure metal. Typical processes for these materials include: (*a*) Vacuum annealing—holding parts at 1,175°F. and minimum pressure for one hour.

(*b*) Brazing of honeycomb structures—heating parts to 1,350 to 1,725°F. in an incrt atmosphere, then quickly reducing the temperature in each instance below the critical point in order to avoid microstructural changes. (With cooling tubes in the retort of the new furnace, the latter temperature drop can be instituted at a rate of 12°/min.)

(*c*) Ageing of solution heat-treated parts—involving use of 950° to 1,075°F. temperatures in varying periods of time with differing atmospheres or pressures.

The furnace is also being used to eliminate the instability of welded titanium parts by heating the latter above their ageing temperatures in inert atmospheres. During this process, the parts are jigged to prevent warpage or distortion.

In work with 17-7 and related forms of stainless steel, the furnace provides adequate protection where annealing temperatures of 1,900°F. and bright heat treating temperatures of 1,400°F. are indicated. Both stainless steels and titanium alloys have been satisfactorily stress relieved with temperatures ranging from 700° to 1,200°F.

Radiation-resistant zirconium ' cans ' for nuclear reactors are probably the most unusual articles that have been vacuum heat treated by North American. This work is extremely critical—not only because zirconium is readily contaminated by other elements at temperatures of 1,000° to 1,500°F., which are usually specified for its heat treatment, but because relatively small quantities of impurities can greatly reduce the radiation resistance of the metal.

CONTINUOUS VACUUM CASTING

NEED for high-temperature alloys for aircraft gas turbines is increasing development of vacuum melting, because it provides the protection which aluminium and titanium need when melted in combination with nickel and cobalt base alloys. Misco Precision Casting Company, Michigan, U.S.A., has collaborated with equipment builders in developing a vacuum furnace permitting continuous operation. Alloy and hot moulds, it is claimed, can be charged through a system of interlocks which maintain constant vacuum in the melting chamber. Cycling is rapid, with no oxidation or thermal shock damage to the melting crucible, states *Steel*, July15.

Automatic Gauge Control of Cold Rolling

Radioisotope Method Controls Strip Thickness

The Robertson four-high cold-strip mill seen from the ingoing side

AUTOMATIC control of the thickness of cold-rolled brass strip is being achieved at the works of D. F. Taylor & Co. Ltd., Birmingham. The mill, built by W. H. A. Robertson & Co. Ltd., and installed two years ago, has now been fitted with the first 'A.G.C. Nucleonic Thickness Gauge' manufactured by Baldwin Instrument Co. Ltd.

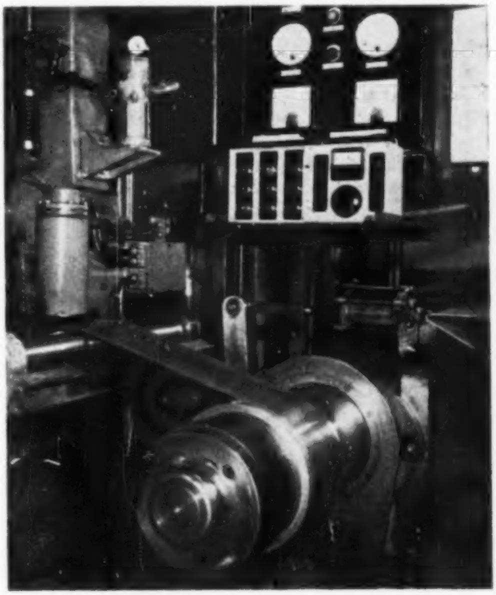
The new Baldwin automatic gauge control has been designed for use on cold strip mills rolling brass, copper and steel and employs the 'bremsstrahlung' radiation produced by a beta-emitting radioactive source, strontium 90. Whereas with beta radiation the maximum thickness of steel measurable is about 0·020 in., with bremsstrahlung a range of about 0·004 to 0·400 in. can be covered.

There are two main variables in metal rolling, thickness and flatness. Both are inter-related and can each be affected by two variable controls, screw-down and tension. Without instrumental control a great deal of skill is required to achieve a combination of screw-down and tension which provides acceptable thickness and flatness. This particular system of A.G.C. is linked with the screw-down adjustment, and the operator is therefore concerned with only one variable control—tension, and one variable effect—flatness.

Principle of the Method

Radiation from the source holder is directed at a detector on the opposite side of the moving metal strip. The radiation in passing through the metal is weakened by an amount which is a function of strip thickness. The detector measures the intensity of radiation penetrating the strip and expresses it in units of thickness. This in turn is converted into terms of a deviation from a pre-set specified thickness.

When the deviation exceeds the preset thickness in either a positive or negative direction, a discriminator triggers relays which cause the screw-down motors to operate. The control action has two discrete functions: (i) to apply small intermittent corrections to the screw-down when the material exceeds the tolerance by a small amount,



Measuring head in position over the outgoing strip. The visual indicators are to be seen in the top right-hand corner of the picture

longer be held in solution. Certain compounds may precipitate out after solidification. When a constituent precipitates out, it may accumulate between grains along grain boundaries, or in the form of minute particles between crystals inside the grains. These particles may thus be present in the slip planes between adjacent crystals. If the same particle is partially embedded in both surfaces of adjoining crystals, it is evident that it will tend to lock those surfaces together and prevent them from sliding freely one on the other. Thus such particles will tend to increase the resistance to slippage between crystals because of this 'keying' effect. With slippage made more difficult, the metal behaves as though it had fewer slip planes, is harder to work and may be considerably stronger. So the end result may be that the mechanical properties of the metal are greatly improved, this being the aim of certain heat-treating cycles.

During cooling, there are not only solids precipitating out of a molten metal, but also solids precipitating out of solids. Just as a solid metal can diffuse into another metal so can a solid precipitate out from another solid. While it is well known that some liquids readily dissolve certain solids, few are familiar with the fact that certain solids can dissolve other solids. It is a fact, however, that if a gold block and a silver block are cleaned carefully and pressed tightly together, the dividing line will gradually disappear, one metal blending or dissolving into the other. While this action will occur at room temperature, it is greatly speeded by heating both metals.

This treatment is known as 'homogenizing.' For many aluminium alloys it is done in the temperature range of 900 to 1,000°F. By this means it is possible to overcome the tendency of certain constituents to segregate or separate to form thin and dense areas. Homogenizing thus is an aid in bringing about proper uniform distribution of the alloying elements and other constituents.

Heat Treatment of Aluminium Alloys

As already indicated it is possible to strengthen aluminium alloys by causing certain constituents to precipitate inside the grains along the crystal boundaries or in the slip planes between crystals, thus hindering slippage and so producing a harder and stronger material. Also resistance to slippage can be increased by controlling the material precipitated between the crystals so that it acts like sharp grit or smoothly like a bearing. It is evident that a material that tends to aid free movement of one crystal on another will produce a softer, weaker alloy, whereas a precipitate that tends to prevent such movement will in turn produce a harder and stronger structure.

Controls, Quenching and Ageing

Examining the recommended heat treatments for strengthening aluminium alloys the author refers to the controls employed to bring about the proper size and distribution of the precipitated particles. First step is to bring the aluminium alloy up to the specified temperature to dissolve the precipitated constituents, so they can later be re-precipitated in the form wanted. The material must be held at the specified temperature for a sufficient period for this dissolving action to occur throughout all portions of the piece being treated. This soaking period constitutes the second step in the heat-treating cycle. The third step is to quench the work rapidly by plunging the part into cold water. Purpose of suddenly dropping the temperature of the part in this manner is to prevent certain constituents from precipitating out, which they would do if cooled slowly.

Quenching from any particular temperature range tends to retain in the metal the structure present just before quenching, and not only prevents the precipitation of certain constituents it is desired to precipitate at that time, but also helps control the constituents wanted out of solution.

Rapid cooling to near room temperature upon quenching produces a supersaturated condition where the material has already dissolved in it more of the constituents than it normally can carry in solution at that temperature. Such a condition obviously is unstable. The result is that certain constituents begin to precipitate from the main mass of the aluminium alloy. This natural ageing occurs at room temperature with many of the aluminium alloys. Certain other alloys must be subjected to artificial ageing, being heated slightly to bring this precipitation to completion within a reasonable length of time. In either case, this controlled re-precipitation is aimed at providing the correct size, character and distribution of the precipitated particles in the aluminium to produce maximum strength and other desired mechanical properties.

It should be mentioned that aluminium alloys hardened in this manner can be made soft and easily workable again by an annealing treatment. However, annealing alone will not produce maximum workability in aluminium alloys that have been heat treated because additional cold working and subsequent re-annealing is required in these instances. Recommended annealing cycles are designed to produce a precipitate in the form of large particles outside the grains along the grain boundaries and not inside between crystals. In this manner, minimum keying effect results and the material is 'soft' because the crystals easily move along their slip planes.

(1) *Metal Treating*, September-October, 1957.

Creep Tests in High-pressure Atmospheres

Research Equipment at G.E.C. Atomic Laboratories

NEW research equipment designed to provide preliminary creep and stress-rupture data on metals and alloys in gaseous atmospheres at high temperatures and pressures has recently been installed in the materials research laboratory of the G.E.C. Atomic Energy Division at Erith, Kent.

Twelve creep-test units have already done valuable work in investigating the properties of magnesium alloys in carbon dioxide atmospheres. They can be readily converted for future work to deal with other materials in other gases. This equipment has been installed to meet the requirement for applied research facilities beyond the range of normal metallurgical laboratory equipment.

Machines for carrying out creep tests in air are standard items of laboratory equipment, and it is comparatively easy to adapt such machines for operation in other atmospheres by enclosing the test specimen in a gas-tight vessel through which the pull-rod passes via a gas-seal. This arrangement can, however, be used only at atmospheric pressure, and it is often desirable to investigate the effects of gas pressures such as prevail in a reactor.

Fig. 1.—Battery of 12 units installed in the laboratories of the G.E.C. Atomic Energy Division for preliminary creep and stress-rupture tests on nuclear reactor materials

The battery of units now installed at Erith was designed for a specifically limited purpose. It is not claimed that it can be used for a complete investigation into the creep behaviour of materials under reactor-operating conditions. Within the time-factor imposed, however, it does provide an efficient means of obtaining, very rapidly, a broad assessment of the suitability of materials for reactor service. More detailed investigation can then be undertaken on materials which pass this test.

In this new equipment, the specimen, the whole of the stressing apparatus and the associated extensometer are enclosed in a vertical cylindrical pressure vessel. This, in turn, is enveloped along part of its length by an electric furnace.

Stainless Steel Pressure Vessel

The body of the pressure vessel, which is of stainless steel $\frac{3}{16}$ in. thick, is 5 ft. long approx. and 4 in. i.d. At its open upper end it is provided with a machined facing flange. The top plate of the vessel is bolted down to a loose flange slipped over the vessel body, a Klingerite gasket being inserted between the top plate and the facing flange to ensure gas-tightness. The upper end of the support rod, from which the specimen is suspended, is welded to the centre of the top plate, while its lower end is provided with a pivoted coupling, a similar coupling being fitted to the top of the pull-rod. Alternative couplings are available such that specimens of either rectangular or circular cross-section can be used. A cylindrical cup, which is a loose fit in the pressure vessel, is welded to the support rod between the top plate and the coupling and is filled with refractory cement so as to provide heat insulation above the operating section.

The loading weights are mounted on a plate welded to the lower end of the pull-rod. To the underside of this plate is attached a bracket carrying a dial gauge, whose operating head rests on the end of a bolt passing through the bottom plate of the pressure vessel, via a rubber gas-seal. The bolt serves as a zero-setting device for the gauge. The gauge reading can be observed through a pressure- and heat-resistant glass window mounted between soft rubber gaskets in a tube welded into the side of the pressure vessel.

Gas is admitted to the pressure vessel through a tube of $\frac{1}{4}$ in. i.d., passing downwards through the top plate and the refractory cement plug. A gas outlet tube, of the same diameter, is welded into the side of the vessel below the operating section.

The 4kW. electric furnace is built in two sections,

and (ii) to apply a radical and continuous correction when the tolerance is exceeded by a larger amount.

Details of Instrumentation

Measuring Unit.—The radioactive source is strontium 90, the beta radiation from which impinges on a metal target giving rise to secondary radiation (X-rays) consisting mainly of continuous spectrum ('white') radiation, known as bremsstrahlung, to be directed at the detector.

A shutter is built into this unit, having three apertures. One aperture is fitted with a standard sample of 0·030-in. steel, another with a thick piece of lead, and the third is left open. A solenoid is connected to the shutter such that its operation can cause any one of the apertures to locate between the source and detector. When automatic standardization comes into operation, either the blank or the steel aperture is moved into position, depending on the setting of the 'range switch,' *i.e.* when the low-thickness range is being used (0·005 to 0·020 in.), standardization takes place with zero thickness in the gap and with the high-thickness range (0·020 to 0·080 in.), the 0·030-in. standard sample is used. The lead aperture is moved into position by the 'manual standardize switch' and is used for the adjustment of infinity setting.

The detector consists of a sodium iodide crystal mounted adjacent to a photomultiplier such that when radiation strikes the crystal, it scintillates to a degree proportional to the radiation intensity. The visible light thus produced is seen by the photomultiplier, which generates a current proportional to light intensity which in turn is proportional to radiation intensity and hence a measure of the thickness of the strip.

The bracket on which the measuring head is mounted is fixed to a steel baseplate and is moved in and out of the measuring position by means of a Baldwin pneumatic cylinder which is actuated either automatically or manually *via* a solenoid valve. The various components are housed in two cast steel units and all electronic equipment in these units is suspended on anti-vibration mountings. The output from the photomultiplier is balanced against a potential representative of the thickness at which the metal should be rolled. If the actual thickness of strip at a given moment equals the 'set thickness,' the input to the amplifier is zero. If, however, the actual thickness deviates from the set thickness, out-of-balance conditions obtain and a signal is fed into the amplifier. A low-gain d.c. amplifier is used, with a high percentage of negative feed-back.

Visual Indicators.—A moving-coil meter measures the output from the amplifier and visually indicates deviations from set thickness as they occur. A strip chart recorder is also connected to amplifier output, producing a permanent record of thickness deviations. Three sets of three lamps, mounted in one unit, indicate: (*a*) automatic standardization, (*b*) shutter position, (*c*) screw-down motors.

Automatic Control

Arrangements can be made to ensure that the A.G.C. system is automatically inoperative when mill speed drops below a certain level, *e.g.* when running up at the beginning of a strip or running down at the end of a strip. Were this precaution not taken, the system would be likely to hunt continuously at low speeds. In the extreme case, if the mill stopped with an over-tolerance strip in the measuring gap, increasing pressure would automatically be applied to the rolls, and considerable damage could occur.

When A.G.C. is switched on at the beginning of a reel, the output from the amplifier is fed to a discriminator unit which has the following operating characteristics:—(1) Whilst strip thickness remains within the 'dead zone' (normally set $\pm 0{\cdot}0003$ in.) the discriminator takes no action.

(2) When thickness enters the 'inner control zone' ($\pm 0{\cdot}0003$ to $\pm 0{\cdot}0005$ in.), intervals of about 2 sec. are fed to relays which in turn cause the relevant screw-down motors to operate for periods of 0·25 sec. until either the thickness restores to the dead zone or moves into the outer control zone.

(3) If the deviation exceeds $\pm 0{\cdot}0005$ in., the discriminator causes the relays and thus the screw-down motors to operate continuously until thickness is restored to within the inner control zone. The limits of the zones can be adjusted in order to meet the requirements of any particular specification.

Standardization of Instrumentation

The instrument makes use of intervals when no strip is passing through the mill, to carry out automatic standardization. As the tail end of a strip passes through the mill, the measuring head is withdrawn and the instrument checks itself against a standard sample which is automatically inserted into the measuring gap. If the equipment is out of adjustment, a servo system automatically applies a correction.

The Cold Strip Mill

The mill is capable of finishing brass strip ranging from 0·004 in. to 15 in. wide, thickness in coil weights up to 5 cwt. and at rolling speeds up to 500 ft. per min. The mill is of the four-high type having work rolls 5¼ in. dia. by 18 in. face width and support rolls 15 in. dia. by 18 in. face width. It is designed for non-reversing operation, handling the coils of brass strip on the batch-rolling principle. The strip thickness of brass being rolled

(*Continued on page* 32)

PHYSICAL METALLURGY

Research at Royal School of Mines

RESEARCH report of the Royal School of Mines, 1954-57, issued by the Imperial College of Science and Technology (University of London), covers the departments of metallurgy; mineral dressing; mining geology; oil technology and applied geophysics. The following extracts are concerned with physical metallurgy.

Aluminium Bronzes

These are essentially copper-aluminium alloys though they often contain additional elements such as manganese, nickel and iron. A binary aluminium bronze containing about 12 wt.% Al may undergo various structural changes in the solid state, some of which resemble those occurring in steels. Thus, at temperatures above 565°C., the copper and aluminium atoms are randomly distributed in a body-centred cubic structure, termed β. If slowly cooled, the β-phase decomposes by eutectoid reaction into a mixture of two other phases, α and γ; under equilibrium conditions this mixture is stable between 565 and 380°C. If, however, β is rapidly cooled, the eutectoid reaction is suppressed, and the structure undergoes two other changes. Firstly, at about 525°C., the aluminium atoms take up selected positions in the body-centred cubic lattice, forming an 'ordered' structure termed β. Then, at about 350°C., the β changes into a martensitic structure termed β′, by a reaction similar to the well-known martensite transformation in steel. Both β and β′ are metastable and decompose slowly at temperatures above 380°C. into the stable $(\alpha + \gamma)$ mixture.

The attainment of the $(\alpha + \gamma)$ structure has been studied by two 'isothermal transformation' methods. One consisted in cooling samples rapidly from above 565°C. to various temperatures, holding them for selected times and then quenching in cold water. In the other method, samples were quenched from above 565°C. to room temperature to produce the martensitic β′, then reheated rapidly, held, and again quenched in cold water. Microscopical examination of the heat-treated samples has provided a fairly complete picture of the approach to equilibrium through the various metastable states.

The effect of manganese on the stability of the β-phase has been investigated, results showing that this element, in amounts up to about 30 wt.%, progressively widens the compositional range over which β is stable, and also lowers decomposition temperature. The 'ordered' phase β, metastable in copper-aluminium alloys, becomes stable over an appreciable temperature range above 410°C. when more than 5 wt.% Mn is present. At 410°C., in these alloys decomposes very slowly into a mixture of α, γ and a ternary compound Cu_3Mn_2Al. The decomposition of β in alloys containing up to 14 wt.% Mn has also been studied by an isothermal-transformation method.

Precipitation Hardening

Many important alloys, including high-strength light alloys, and creep-resisting alloys used in gas turbines, owe their strength largely to age-hardening or precipitation-hardening, obtained by causing precipitation phenomena under controlled conditions in supersaturated solid-solutions. A systematic investigation of the constitution and precipitation-hardening characteristics of aluminium alloys containing copper, magnesium, manganese, iron and silicon in various combinations and concentrations has long been in progress. Work on the ternary systems comprising aluminium and copper with iron, manganese or silicon has been completed. The investigation has now been extended to two quaternary systems, namely aluminium-copper-magnesium with manganese or silicon. So far, the work has been restricted to heat-treatment, microscopical examination, hardness testing and tensile testing, but it is expected that other methods of investigation, such as electron microscopy or specialized X-ray diffraction techniques, will soon be applied to the problem. A similar investigation of copper-beryllium alloys, and ternary alloys of these elements with cobalt or chromium, is also in progress, particular attention being paid to the effect of composition and treatment on fatigue-resistance alloys.

High-tensile Brasses

High-tensile brasses (or manganese bronzes) were developed to meet the demand for non-ferrous alloys with the same density and strength as mild steel but better resistance to corrosion. The alloys are used mainly in the cast condition, particularly for marine purposes, a notable example being ships' propellers. Unfortunately, the stronger of the alloys, which are composed of the β-phase, sometimes crack unexpectedly while under stress, especially when in contact with sea water. It occurs along the crystal boundaries, whereas the path of a normal fracture crosses the crystals. Because of the risk of failure occurring in this way, the application of the β alloys has been restricted, and less strong alloys containing a mixture of the α and β phases have been preferred, as they are not prone to stress-cracking.

The basic mechanism of the cracking phenomenon is being investigated. The practical aspects are being studied, too, with the aim of developing alloys that will not be susceptible to the effect.

and can be split by unbolting two vertical clamping plates, thus allowing the pressure vessel to be removed. The nichrome heating elements are carried in slots in the inner faces of bricks of high-temperature insulating material which are assembled in the form of a hexagon surrounding the pressure vessel, the space between the element bricks and the furnace casing being filled with refractory cement. The two heating elements, one in each half of the furnace, are connected in parallel to a 240-volt, single-phase, 50-c/s supply.

During normal operation, two chromel alumel thermocouples are employed. One is mounted directly on the specimen and is usually connected to a recording instrument, its leads being taken upwards through the gas inlet tube from which they issue through a gas-seal. The second is mounted adjacent to the furnace winding and is connected to an Electroflo temperature controller housed in a louvre-ventilated casing built into one of the two terminal chambers.

When the stressing apparatus, with the test specimen mounted in position, has been lowered into the pressure vessel, the top plate is sealed down. The vessel is then thoroughly flushed with the gas being used as the test atmosphere before being brought up to pressure. The supply to the furnace is adjusted to raise the temperature of the specimen rapidly to the required value, and it is then maintained at this level by the temperature controller.

When stable conditions have been established, extensometer readings are taken at suitable intervals, the results being plotted as percentage creep against time. The total duration of the test varies according to the particular requirements, but is normally between 150 and 1,500 hours.

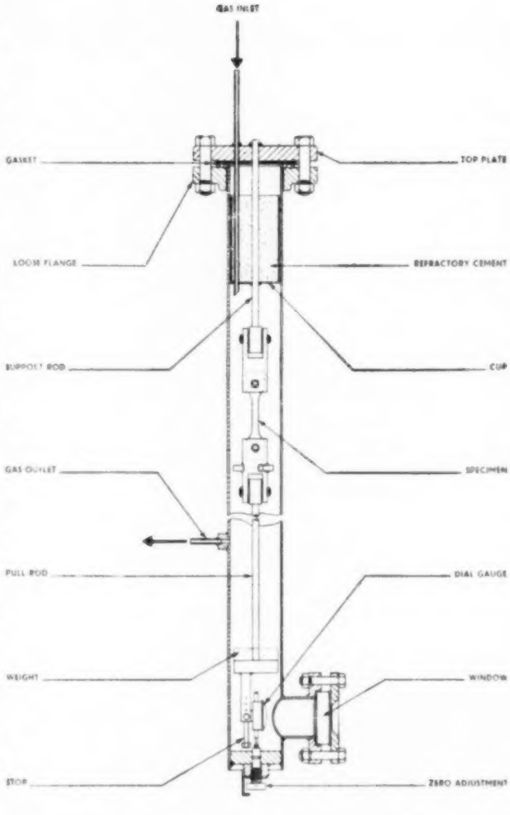


Fig. 2.—Cross-section through the pressure vessel of one of the units

Automatic Gauge Control

(*Concluded from page* 30)

on the present installation at D. F. Taylor & Co. Ltd. is 0·007 to 0·030 in. on the ingoing side and the normal finished gauge is 0·005 in. The minimum stable automatic control tolerance is $\pm 0{\cdot}00015$ in. and the normal working tolerance in this particular installation is $\pm 0{\cdot}0003$ in.

Coil Feeding Equipment.—Coils incoming to the mill are received in a decoil box equipped with adjustable side guides to accommodate various widths of material. Strip is fed from the decoil box and over an idle deflector roll mounted on the combined feed table and sticker unit. The feed table is equipped with adjustable side guides to ensure that the strip is accurately guided into the bite of the work rolls and a pneumatically operated wiper press which removes dust from the surfaces of the strip and allows back tension to be applied. The feed table is mounted on slides carried in the roll housings and once the strip is clamped in the wiper press the table is thrust forward by an air cylinder forcing the leading edge of the strip between the work rolls.

Recoiling Equipment.—On the outgoing side of the mill the roll housings are spanned by an outlet table carrying strippers which extend right up to the bottom work roll. Strip issuing from the mill travels along the stripper plate, past the A.G.C. thickness gauge and over an idle deflector roll to be received by the recoiling reel which is 12 in. nominal diameter.

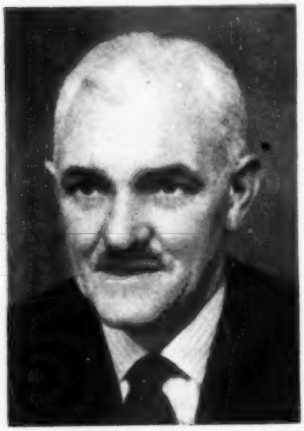
Coil Handling System.—A complete conveyor system is provided to return coils by gravity from the outlet to the ingoing side of the mill for further cold reduction. The system can accommodate up to 30 coils. A combined coil elevator and down-ender is operated automatically by the coils during their passage.

News of the Month

DROP FORGERS ELECT PRESIDENT

Mr. J. H. Swain voted to office for 1958

AT their meeting last month, the governing council of the National Association of Drop Forgers and Stampers unanimously elected Mr. J. H. Swain President of the Association for 1958. Mr. Swain, who is managing director of the Stampings Alliance Ltd., will take office at the annual general meeting to be held on the 25th of next month.



Mr. J. H. Swain

His previous services to the Association are so well known that elaboration in detail is unnecessary. From as far back as the 1930s he has been connected with many of the Association's committees, but his name is best remembered for his efforts to maintain economic prices for the industry's products. At present, he is the chairman of the Commercial Committee, and is also a member of the Technical Committee.

American Metals Exhibitions

OVER 64,494 people from 42 nations attended the National Metal Exposition and Congress at its 39th Metal Show held recently in Chicago (U.S.A.). The show was held in the International Amphitheatre, and more than 175 scientific sessions convened at nearby hotels.

Mr. W. H. Eisenman, managing director of the show, has announced that in 1958 it is to be held in Cleveland, Ohio, from October 27 to 31.

Adding to the international aspect of the Metal Show were 535 scientists from overseas attending the 2nd World Metallurgical Congress sponsored by the American Society of Metals, of which Mr. Eisenman is the secretary. Some 250 of these visitors spent two weeks touring 70 American industrial plants and educational institutions prior to the Chicago meeting. A group of 20 from Russia and other iron curtain countries came to Chicago attending the open sessions there.

The 3rd World Metallurgical Congress is to be held in Chicago in 1962.

The next major industrial show sponsored by the A.S.M. will be the Southwest Metal Exposition and Congress to be held in Dallas, Texas, from May 12 to 16, this year.

A HAPPY AND PROSPEROUS NEW YEAR

The editors, the advertisement manager and the staff extend to all readers, advertisers, contributors and other friends in the industry at home and overseas, sincere and cordial good wishes for their happiness and greater prosperity in 1958.

NATIONAL COUNCIL FOR TECHNOLOGICAL AWARDS

THE National Council for Technological Awards, in their first report published recently, say that the Government's plan to produce the necessary supply of technologists through the technical colleges can only succeed if the colleges, industry and the Council are able to pool their experience and ideas and produce suitable courses in the various technologies.

The report describes the work of the Council since it was set up at the end of 1955, under the chairmanship of Lord Hives, to create and administer for technical college students awards of high standard, equivalent, in fact, to university honours degrees.

In his foreword to the report, Lord Hives states that on November 21 there were 965 students at 11 colleges attending 37 courses recognized as leading to the Diploma in Technology.

The Council are anxious to see that all courses leading to the diploma not only reach the required standard in a technology, but also cover liberal studies and informal activities. To provide for this a large amount of pioneer work has to be done and for the moment the Council have been satisfied to accept a statement of the intention of a college on the development of a liberal approach in the curriculum, rather than to insist on the submission of detailed syllabuses in all cases. They hope that when the recognition of courses is reviewed these studies will have become an integral part of the course.

Important part played by industrial training

The Council regard a course leading to the Diploma in Technology as a complete entity, the industrial training being just as much a part of the course as the academic study. The report emphasizes that the integration of academic and practical training in industry must be an essential part of any course. The Council also consider it to be of paramount importance that students continue their academic studies during periods of industrial training. Some colleges are attempting to solve these problems by arranging for members of staff to visit students at their place of work while they are in industry.

It appears that smooth crystal boundaries favour cracking, and that alloying additions which result in the formation of small keying particles at the boundaries can prevent it. Although the high-tensile brasses are very strong at room temperature, they soften rapidly as the temperature is raised. For example, at 300°C. under a tensile stress of only 3 tons/sq. in., an alloy may gradually extend or 'creep' and ultimately fail in about 20 days. One of the recognized ways of improving creep resistance is by incorporating a dispersion of hard and stable particles of a compound in the metallic structure. Particles that confer resistance to inter-crystalline cracking also stiffen the alloy against creep, and this means a 100% improvement in creep resistance has already been obtained.

Metallurgy for Atomic Reactors

Transformation in Uranium-Molybdenum Alloys: Uranium exists in three allotropic modifications, designated α, β and γ respectively, and the constitutional relationships between these modifications are known approximately for the uranium-molybdenum system. The kinetics of the transformation from one modification to another are being investigated by determining transformation rate curves based on measurements of dimensional changes in samples isothermally treated at various temperatures.

Neutron Irradiation of Metals: When a metal specimen is bombarded with neutrons by being placed in a nuclear reactor, atoms are displaced from their lattice sites, and a complex system of point defects is produced. In addition, the metal becomes radioactive, and chemical impurities are introduced by transmutation. As a result of these changes, the properties of the metal may be considerably modified.

An investigation is being carried out into the effect of irradiation on the ductile-brittle transition temperature of some of the body-centred cubic metals. Molybdenum has been chosen for the main part of the investigation because it has a relatively low specific activity after irradiation, and is readily available and easily worked. The irradiation of both annealed and cold-worked specimens is being studied. The changes of transition temperature are being investigated mainly by tensile testing, but other experiments now in progress may help towards an understanding.

Hydrogen in Uranium: Metals, in general, corrode at a rate that is either approximately constant or decreases with time. Some metals, however, notably alloys of uranium and zirconium, under some conditions show a low rate of corrosion at first, and then after a period which may be months, the corrosion rate may suddenly increase. This is known as breakaway corrosion. So far it is unexplained, but clearly it may have serious consequences in connection with the break-up of nuclear-reactor elements, as the increase in the corrosion rate may be a thousand times or more. There appears to be a correlation between the hydrogen content of the metal and breakaway corrosion phenomena, but the exact nature of this relation is not clear. An investigation is being undertaken to correlate the hydrogen content of uranium, the state of the gas in the metal, and the corrosion characteristics of uranium and its alloys.

Liquid Metals: To improve existing fuels for reactors, ternary uranium and thorium systems are being investigated. Two methods of fuel addition considered include the solution of the fuel in the heat-exchange medium, and the 'breeder blanket' technique. The first method entails the use of a molten metal, which circulates between the core and the heat-exchange boiler; the fuel (uranium) is introduced into the reactor as a solution in the liquid metal, which thus serves to remove fission products from the core. In the second method, metallic thorium, either in solution in a liquid metal or in the form of a slurry, surrounds the core of the reactor and breeds the fissile isotope U_{233} by capture of neutrons from the core.

For both the above methods, the liquid metal solvent being considered is bismuth, and initially an attempt is being made to vary the solubility of uranium in bismuth by means of ternary additions. Also the effect of ternary additions on the habit and mode of nucleation of bismuth-thorium intermetallic compounds is being studied. Because of the possibility that lithium may prove to be an effective liquid metal, the solubility of uranium in lithium is also being determined.

Unfortunately, the solubility of uranium in bismuth at the working temperature of a reactor is too low to permit an adequate amount of fuel to be brought into the reactor in solution; on the other hand the solubility is too high to allow a stable slurry to be formed as this requires a virtually negligible solubility of the particles in the liquid. If there is appreciable solubility, growth of the larger particles will occur at the expense of the smaller ones and clogging of the system may result.

Previous investigations into the bismuth-thorium system have shown that a slurry is the only practical medium for introducing thorium into the blanket. Under these conditions, the thorium forms a compound with the bismuth, probably Th_3Bi_5. The object of the research is firstly to minimize the interaction of this compound with liquid bismuth, and secondly to find how the crystal structure of the compound is modified by additions of other metals, particularly those likely to occur in the bismuth under practical conditions as fission products.

Cemented Oxide Tools Research

Coventry firm install machine tool unit

A COVENTRY firm, Wickman Ltd., have recently installed a machine-tool unit at their Upper York Street works to carry out tests on the applications of cemented oxide tools. The unit comprises three machines: a Max Müller Eltromatic lathe of special design, a Heller FH 160 milling machine, and a Carlstedt deep-hole boring machine.

Eltromatic Lathe

The Eltromatic lathe has been specially designed and constructed by Max Müller in collaboration with Wickman. It is capable of infinitely variable spindle speeds from 500 to 5,000 r.p.m. with the present headstock. At a later date, another headstock will be substituted to double the maximum speed. The drive is supplied by a 30-kW., 40-h.p., thyratron-valve-controlled d.c. shunt motor having a variable speed from 375 to 3,000 r.p.m., controlled in a ratio of 1: 8. Any preset cutting speed up to 2,400 ft./min. can be constantly maintained by automatic potentiometer control on the cross slide. If the spindle speeds are regulated independently of the cross slides, then cutting speeds far in excess of 2,400 ft./min. can be obtained. The spindle, motor and pulley are dynamically balanced. The centre height of the lathe is 16 in., and the distance between centres 5 ft. A specially designed running centre, suitable for the load to be imposed at 5,000 r.p.m., is carried in a rigid tailstock hydraulically operated so that a constant pressure can be maintained at the centre-point irrespective of any expansion of the workpiece.

The cross slide is designed to cater for normal cantilever or, alternatively, tangential type tooling. The spindle of the machine is adapted to take a milling cutter so that experiments in flycutting can also be carried out with cemented oxide tools.

Instruments for recording r.p.m., cutting speeds, amperes and kilowatts are grouped in a panel to the left of the headstock. On a separate instrument table, insulated from the floor, there is recording equipment for the cutting forces measured by the tool force dynamometer. Also mounted on this table is a new Taylor, Taylor and Hobson, Model 3, Talysurf instrument, with full recording equipment for the measurement of the surface finishes produced on the workpiece.

Heller FH 160 Milling Machine

The main drive motor is 45 h.p. and the drive is transmitted to the machine through an 18-speed gear box to provide a range of speeds from 28 to 900 r.p.m., selected by electro-mechanical disc clutches. The spindle is provided with a brake to reduce running-down time. Movement of the table and knee is made by mechanical lead-screws driven by hydraulic motors, with full compensation for climb milling. The table feed along and across is infinitely variable between ¾ and 140 in./min., and up to 35 in./min. in a vertical direction.

The complete control system for the machine is grouped on a panel at the front of the machine.

Carlstedt Deep-hole Boring Machine

The Carlstedt machine has been installed for a research programme governing the production of holes. The main features of the machine are the provision of self-aligning cutters to ensure concentricity of the hole, combined with a very high coolant pressure of 250 lb./sq. in. with a flow of 300 gal./min. The main spindle has a maximum speed of 2,500 r.p.m. and is driven by a 38-h.p. motor.

Control of the chip size is by infinitely variable feed mechanism.

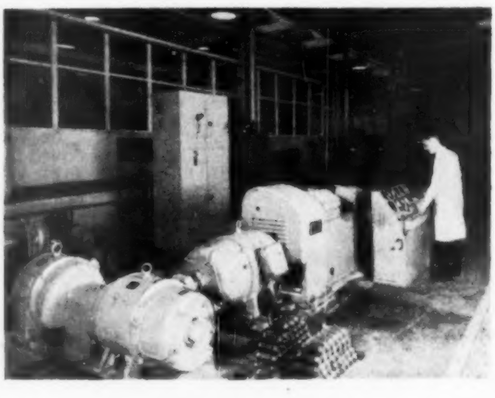
The pressure head design of this machine is unique and its capacity is from ¾ to 4¾ in. dia. up to a maximum length of 4 ft. 7 in.

The new department will be under the control of Mr. R. N. Cook, M.I.Mech.E., M.I.Prod.E.

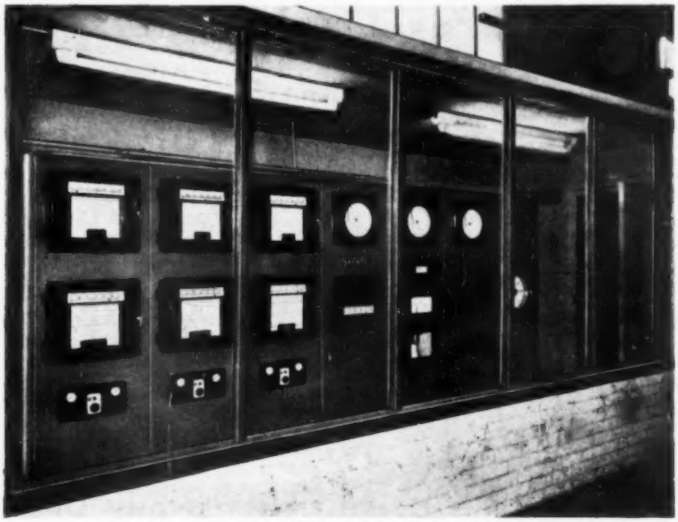
SALES AGREEMENT

UNDER a new agreement made on terms acceptable to both parties the Wilmington, Del. (U.S.A.) firm of E. I. Du Pont de Nemours & Co. Inc. have modified the arrangements under which Durham Raw Materials, 1-4 Great Tower Street, London, have been the sole distributors of Neoprene in the United Kingdom.

The changeover is in two parts, spread over a year. From the beginning of this month, sales of Neoprene have been made in the name of Du Pont, with Durham Raw Materials Ltd. acting as sales agents. On January 1 next, the Du Pont Co. will assume full control of all Neoprene sales in the U.K.



Two views of the Wickman research and development department. Lower left, the Max Müller Eltromatic lathe is seen in the foreground, and, lower right, the Carlstedt deep-hole boring machine.



AUTOMATIC CONTROL PANEL AT STEELWORKS

ILLUSTRATED in the photograph above is the George Kent Ltd. installation at the South Durham Steel & Iron Co.'s works. Designed to provide an automatic control and instrumentation panel for a Gibbon Bros. normalizer, the equipment comprises a series of Multelec temperature recorders and recorder-controllers with Mk.20 sub-panels and a ring-balance recorder.

George Kent's have also provided an instrumentation and automatic control panel for some Priest reheating furnaces installed at the same works. The panel automatically controls the temperature at which the furnaces operate.

PRODUCTION EXHIBITION

LORD MILLS, K.B.E., the Minister of Power, will open the third Production Exhibition and Conference, which will be held at Olympia, London, from May 12-21. The president of the exhibition and conference will be the Earl of Halsbury, F.R.I.C., F.Inst.P., M.I.Prod.E., President of the Institution of Production Engineers, sponsors of the project. The exhibition will again be organized by Andry Montgomery Ltd., 32 Millbank, London, S.W.1.

The theme of the exhibition and conference is 'Production Fights Inflation,' and the purpose is to place before the public examples of some of the production technology employed in this country, and to show how the work of scientists, designers and development engineers is utilized.

OBITUARY

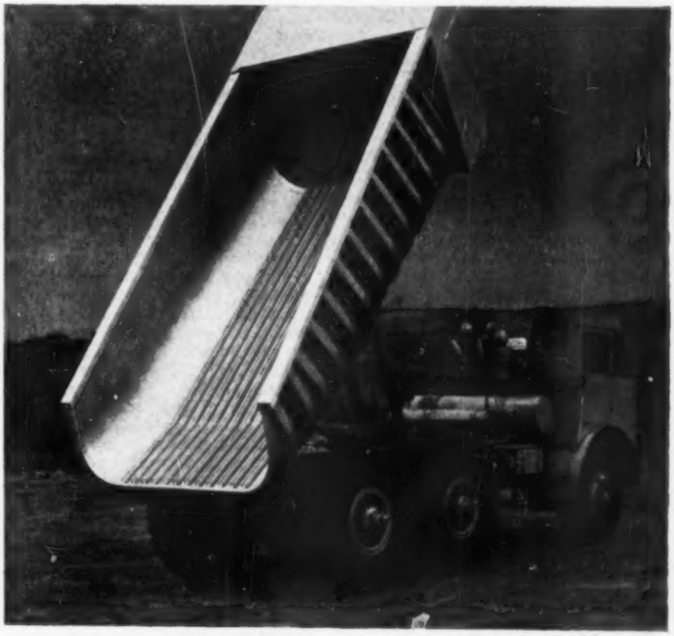
BROWN. The death has occurred recently at West Hill, Bowdon, Cheshire, of Mr. J. Harold Brown, a former chairman of Sanderson Bros. and Newbould Ltd., Newhall Road, Sheffield. He was 84. Mr. Brown retired from the board at the end of 1955. He had been chairman since 1938 and a director for 25 years.

GALVANIZING CONFERENCE

THE fifth international conference on hot-dip galvanizing is to be held in Brussels, Belgium, during June of this year. The conference, the first to be organized by the recently formed European General Galvanizers Association, for whom the Zinc Development Association, 34 Berkeley Square, London, W.1, acts as the Secretariat, will be taking place at the same time as, and will be under the patronage of, the Brussels World Fair. Experts on galvanizing from many countries will be presenting papers on various aspects of the subjects and works visits in Belgium and Holland are being arranged by local associations.

ALUMINIUM ALLOY DUMPER BODY

CONSTRUCTED of Noral aluminium alloys made by the Northern Aluminium Co. Ltd., Banbury, the heavy duty dumper body illustrated in the photograph on the right is an example of the increasing use of this material for applications where light weight allied to strength is required.



STAFF CHANGES *and* APPOINTMENTS

Mr. F. H. Parkes, who is commercial manager of **The Blackheath Stamping Co. Ltd.**, has been appointed a director of the company.

* * *

Mr. N. C. Lake has been appointed a director of **Head, Wrightson & Co. Ltd.,** with the position of deputy managing director. He will be responsible for the co-ordination of Head, Wrightson group sales to the iron and steel industry. Mr. Lake hitherto has been managing director of the Head Wrightson Machine Co. Ltd.

* * *

The Foseco Group of Companies, Long Acre, Nechells, Birmingham 7, have recently made the following changes in their organization: Foundry Services (Overseas) Ltd. will in future operate as **Foundry Services International Ltd.** The board will comprise Dr. K. Strauss, Mr. E. Weiss, Dr. D. V. Atterton, Mr. G. E. Cobby, Mr. R. D. Hume, Mr. R. A. Miller and Mr. D. A. Patterson.

Foundry Services Ltd. will continue to operate as formerly, but Mr. A. G. T. Chubb and Mr. J. C. Noon have now joined the board.

* * *

Acheson Industries (Europe) Ltd. announce that Mr. S. Mackenzie-Owen has been appointed unit manager of Acheson Colloiden N.V., Scheemda, Netherlands. Mr. Mackenzie-Owen, after a short period at the firm's London offices, will move to Scheemda in the new year to assume full responsibility for the Dutch company.

Mr. Mackenzie-Owen took the B. Comm. degree course at the University of London and then served an apprenticeship with an engineering concern in Scotland. He joined David Brown & Sons (Huddersfield) Ltd., and subsequently was promoted to regional sales manager.

During army service, Mr. Mackenzie-Owen was awarded the M.B.E. for work on the reorganization of a number of R.E.M.E. workshops.

* * *

Mr. W. H. Apthorpe, the managing director of the **Cambridge Instrument Co. Ltd.,** 13 Grosvenor Place, London, S.W.1, has retired from executive duties, but he has retained his seat on the board, and will continue to be available for special duties as deputy chairman.

Mr. Apthorpe started his training with the company in 1900, and for seven years gained experience under the late Sir Horace Darwin. He resigned in 1907 to obtain further experience in association with Mr. Clarke-Fisher and the late R. W. Paul, and three years later was appointed assistant to the late Prof. Donnon at Liverpool University, where he was able to continue his technical education.

In 1914 Mr. Apthorpe returned to Cambridge Instruments to take charge of their testing department, and in 1919 he was appointed to the position of works manager at the London factory. He was appointed a director in 1925.

Mr. H. C. Pritchard

Mr. Apthorpe has been succeeded as managing director by **Mr. H. C. Pritchard,** B.A., F.R.Ae.S., M.I.N., who formerly held a senior position with Elliott Bros., and has had a distinguished scientific and administrative career. After taking high honours at Oxford he went to the Air Ministry on research and development work and in 1939 was appointed head of the Navy Section at the R.A.E. After the war he became head of the Blind Landing Experimental Establishment at Martlesham for a period and then returned to the R.A.E. as head of the Instrument and Photographic Department. In 1949 Mr. Pritchard was seconded to the Australian Government as chief superintendent of the Woomera rocket range and after a successful period in that capacity returned to this country to join Elliott Bros.

* * *

Mr. A. J. Somers, F.R.I.C., has retired after 36 years with **Borax Consolidated Ltd.** Since February 1946 he has been a member of the board of the parent company, now Borax (Holdings) Ltd.

Originally engaged as a scientist, Mr. Somers spent many years between the wars investigating and promoting the industrial uses of borates; he became sales manager of the company in 1940. At the end of the war he travelled widely overseas, reviewing the company's interests in many parts of the world.

His many friends in the scientific world, and in the numerous British and overseas industries, in whose technical problems he took a close and constructive interest, will wish him all health and happiness in his retirement.

* * *

Mr. A. Russell, M.B.E., A.M.I.P.E., has relinquished the position of manager of Stamping Alliance Ltd., Shenstone, and has taken up an appointment as managing director of **Charles Thomas & Co. Ltd.,** stampers and edge tool manufacturers, Wainwright Street, Aston, Birmingham 6.

* * *

Mr. C. J. Staddon, D.F.H., A.M.I.E.E., has relinquished his appointment with McLellan & Partners to join **John Miles & Partners (London) Ltd.,** consulting engineers, of 76 Cannon Street, London, E.C.4, in their electrical engineering department.

* * *

Mr. Raymond Lee Pearson has been appointed a director of **Newbold & Burton Ltd.** and **Lawson Ward & Co. Ltd.**

* * *

Mr. P. J. A. Lachelin has been appointed a director of **John Dale Ltd.** and elected deputy chairman.

* * *

The retirement has been announced of Dr. J. W. Hurst, deputy chairman and managing director of Bradley & Foster Ltd., Darlaston; Bradley (Darlaston) Ltd.; Bradley (Concrete) Ltd.; and Arblaster & Co. Ltd., Kings Hill, Wednesbury, on grounds of health.

Dr. Hurst will remain in an advisory and consultative capacity with the group and will also continue as a director of the parent company, T. Staveley Coal & Iron Co. Ltd.

Consequent upon the retirement of Dr. Hurst, Mr. G. E. Lunt, only son of the late Mr. G. T. Lunt who was managing director from 1923 until his death in 1949, has been appointed managing director.

Mr. G. E. Lunt returned to the company after completing his military service in 1946. He was appointed general works manager in 1949 and a director in 1954. He is president of the Foundry Trades Equipment and Supplies Association and hon. treasurer of the Staffordshire Iron and Steel Institute.

Financial Support for Trevelyan Scholarships

A NUMBER of industrial companies are to provide financial support for scholarships of a new kind to enable selected boys to attend Oxford and Cambridge Universities. Dr. G. M. Trevelyan, O.M., has kindly agreed that the awards should bear his name.

The Trevelyan Scholarships will be open to boys of British nationality receiving full-time education at schools in the United Kingdom and will be subject to successful candidates securing admission to one of the colleges at Oxford or Cambridge. Their value will be £450 per annum for three years, extended to four years in exceptional circumstances. About a dozen scholarships can be awarded annually at each university for the initial five-year period of the scheme.

The sponsors hope that these scholarships will encourage boys to pursue a broader range of studies in the sixth form, whether related to their own special subjects or not, without impairing their chances of going to a university through lack of financial support.

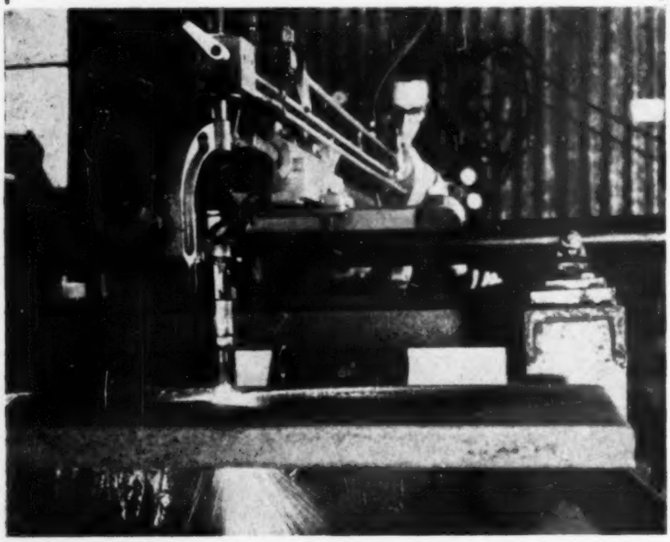
It is intended to make the first selections in November this year by a committee consisting of representatives of Oxford and Cambridge Universities and industry in equal numbers under a permanent chairman, and details of the scholarships have already been circulated to all members of the Incorporated Association of Head Masters. The full list of sponsoring firms is not yet complete.

A steering committee has been established, representative of industry, schools, and the two universities, under the chairmanship of Sir Walter Benton Jones. Mr. R. Peddie, of 17 Westbourne Road, Sheffield 10, is secretary of the committee.

NEW DATE FOR EXHIBITION

THE Domestic Equipment Trades Fair is to take place at the National Hall, Olympia, from September 2 to 11, inclusive, instead of in August as previously decided. Applications for further details should be made to the organizers, B. & C.D. Trade Exhibitions Ltd., 194-200 Bishopsgate, E.C.2. Telephone Avenue 1444.

Flame Cutting Replaces Forging



Fabrication from steel plate has replaced casting and forging from iron for a number of components at the Clydebank factory of Dawson & Downie Ltd.

The firm manufactures pumps for a number of industries and, over the past two years, the introduction of flame cutting machines supplied by British Oxygen Gases Ltd. has effected a considerable saving in time. For example, during the fabrication of pump columns, a time of approximately ten days formerly elapsed before the casting was available for machining, prior to assembly. Now, a Beagle profile cutting machine is used to fabricate the component from steel plate of up to 1¾-in. thickness. With the application of flame cutting, the component can be shaped, welded and ready for machining in 1½ days.

The Beagle machine is used in the fabrication of a wide range of components which include crank case end covers, suction chests, gear box doors, filter chamber doors, glands, discharge and suction companion flanges, exhaust companion flanges, and crank distance pieces. Flame cutting with the aid of the machine has also replaced forging for such components as crankshafts, crankwebs, steam stool flanges, pump swivels, oil throwers and column palms.

The firm have adopted a novel method for shape tracing. A sheet of light-coloured matt Formica is used to form the tracing table top, and the shape required to be cut is described in actual size in black pencil on this surface. The use of the Formica sheet ensures that the tracing wheel is in actual contact with the drawn line, and the operator is afforded better vision. When another shape of different size is required to be cut, the old pattern is merely erased from the Formica sheet.

Research Paper for the U.S.A.

RESEARCH on the impact properties of cast steels at low (sub-zero) temperatures which has been undertaken by the British Steel Castings Research Association during the past three years has recently been published by the Iron and Steel Institute in a paper entitled 'Low Temperature Impact Properties of Cast Steels,' by W. J. Jackson and G. M. Michie. The aim of this investigation has been to establish for the first time reliable and comparable data on the impact properties of a wide range of commercially available grades of low alloy and carbon steels which are supplied as castings for numerous engineering applications involving low-temperature conditions of service. The results of this research have already been well received by B.S.C.R.A. members in this country and in the Dominions, and now 2,500 reprints of the paper have been ordered by an international metallurgical company for distribution in the U.S.A.

New Plant and Services

Electro-gas Heating Equipment

Illustrated in Fig. 1 is the new self-contained electro-gas equipment, part of the Stanelco range manufactured by Standard Telephones & Cables Ltd., Industrial Supplies Division, Sidcup, Kent.

This multi-burner heating equipment for soldering, brazing, annealing and hardening has a built-in process timer, and the heating cycle can be initiated by foot switch or push-button. The work-table is larger than on an earlier bench model, permitting sliding jigs to be fitted easily.

With two jig trolleys sliding in and out of the burner zone it is possible to load components during the actual heating cycle. The self-contained model shown here is ready for mounting directly in the production line. Town's gas, compressed air (at any pressure over 35 lb. per sq. in.) and a 5-amp. 200/250 v. 50 c/s a.c. electricity supply are all that are required.

The Stanelco range comprises equipment for high-frequency induction heating, electro-gas heating, resistance heating, and toggle presses.

Hand-operated Hydraulic Elevating Trolley

Farrow & Jackson Ltd., 41-42 Prescot Street, London, E.1, are now marketing their new hand-operated hydraulic elevating trolley. Its simplicity makes it a 'maid-of-all-work' for any type of factory. The standard model has a top area of 33 in. by 21 in., it is 29 in. high and in its fully raised position extends to a height of 48 in.

It will lift loads of up to 8 cwt. to the full height of 48 in. in 35 seconds and is so light in operation that the handle can be easily pumped. Lowering is achieved by giving the handle a half-turn in an anti-clockwise direction. Clips are provided for housing the handle when not in use and the trolley is fitted with two fixed and two swivel wheels. Standard finish is in deep bronze green but other colours can be had to special order.

A variety of non-standard tops which can be designed to suit individual use are available. Examples of these include stainless steel or Warerite tops for the food or pharmaceutical industries, jig-type tops for inter-production movement, and roller-conveyor tops for use with permanent conveyor systems.

Flaw Detection Fluid and a Mechanical Seal

Flaw detection fluids made by the Manchester Oil Refinery Group, Trafford Park, Manchester, 17, are now available in handy, pressurised containers. The fluids include a recently introduced product—Britemor fluorescent ink.

The 'ink' provides an extremely sensitive and searching means of determining the existence of surface cracks and faults in manufactured components. Used in conjunction with a suitable source of ultra-violet light, fluorescent ink reveals flaws clearly and unmistakably as brightly glowing lines and areas (Fig. 2). It can be successfully used for the examination of all types of metallic materials and most plastics.

This group of companies also recently introduced a mechanical seal for rotary shafts manufactured by Flexibox Ltd., a member firm of the group. The seals have found wide application in the aircraft industry as an effective and efficient means of preventing leakage from the glands of rotary shaft equipment. Of unique design, the seal has been employed at shaft speeds up to 30,000 r.p.m., at temperatures down to minus 60° C. and under conditions involving pro-

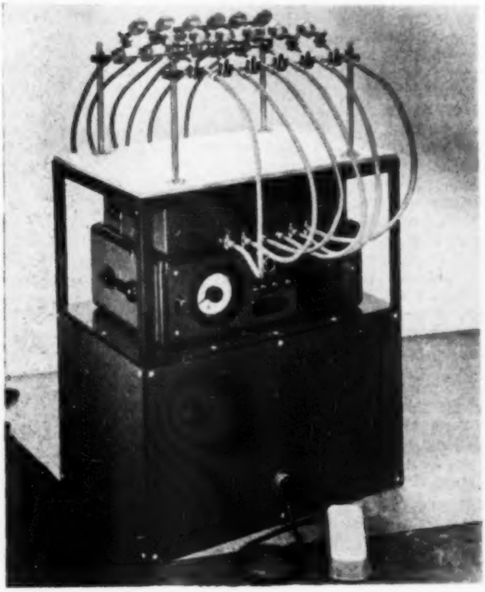
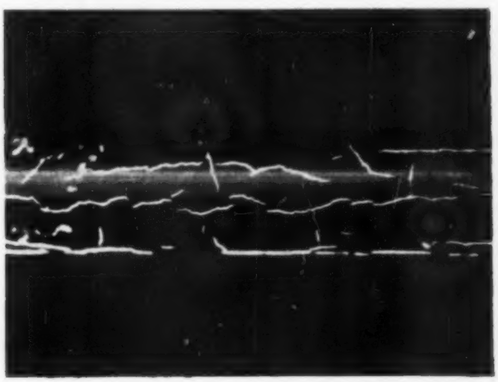


Fig. 1 (left).—Electro-gas heating equipment

Fig. 2 (below).—This photograph, taken in ultra-violet light, illustrates cracks in a stainless steel bar brilliantly indicated by fluorescent ink



Forthcoming Events . . .

January 15
Swansea and District Metallurgical Society. 'Recent developments in iron and steel works practice,' by W. F. Cartwright (Steel Co. of Wales). 7 p.m. at the Central Library, Swansea.

January 23
Birmingham Metallurgical Society. 'Electric furnace developments,' by P. F. Hancock. 6.30 p.m. at the Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham 2.

January 24
Institute of Metals (N.E. Metallurgical Society). 'Some views on the use of oxygen in steelmaking,' by T. F. Pearson. 7.15 p.m. at the Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough.

February 4
Institute of Metals (Oxford Section). 'Technical control of some metalworking processes,' by Prof. A. R. E. Singer. 7 p.m. at the Cadena Café, Cornmarket Street, Oxford.

February 4
Institute of Metals (S. Wales Section). 'Secondary metal recovery,' by H. J. Miller. 6.30 p.m. at the Department of Metallurgy, University College, Singleton Park, Swansea.

February 6
Institute of Metals (London Section). 'Corrosion by liquid metals,' by B. R. T. Frost, at the Institute's premises, 17 Belgrave Square, London, S.W.1. 6.30 p.m.

February 6
Birmingham Metallurgical Society. 'Porous and infiltrated metals,' by J. E. Elliott. 6.30 p.m. in the Byng Kendrick Suite, College of Technology, Gosta Green, Birmingham.

February 8
Swansea and District Metallurgical Society. 'The production of alloy steels,' by F. T. Bagnall (Samuel Fox & Co. Ltd., Stocksbridge). 6.30 p.m. at the Central Library, Swansea.

February 10
Institute of Metals (Scottish Section). 'Recent developments in the foundry,' by D. V. Atterton. 6.30 p.m. at the Institution of Engineers and Shipbuilders, 39 Elmbank Crescent, Glasgow C.2.

February 13
Institute of Metals (Liverpool Metallurgical Society). 'Wear in cast iron,' by H. T. Angus. 7 p.m. in the rooms of the Liverpool Engineering Society, 9 The Temple, Dale Street, Liverpool.

X-ray Service to Industry

THE radiological inspection service operated by the X-ray Division of Palmer Aero Products Ltd. at Penfold Street, London, N.W.8, for the aircraft, welding, foundry and associated industries has recently been considerably extended.

With the installation of new radiographic equipment of the latest design and specially designed handling and setting equipment, the company will be able to deal quickly and efficiently with a wider range of work.

A new test house is now available for X-rays (3 in. maximum steel penetration), gamma-rays, and magnetic and fluorescent crack detecting processes on all types of castings and welded parts up to one ton in weight.

Pena Buys Welsh Metal Company

CONTROL of Cordes (Dos Works) Ltd., Newport, Mon., a company engaged in the manufacture of nails and the re-rolling of light gauge rails, has been acquired by Pena Copper Mines Ltd.

Stockholders of Cordes will receive approximately £35,000 in Pena preference and ordinary shares in exchange for their present holding.

NEW COMPANIES

'Ltd.' is understood, also 'Private Co.' Figures = Capital, Names = Directors, all unless otherwise indicated.

CROFTERS ENGINEERING CO., Toothill Bridge Works, Bury Road, Bolton. November 13. £5,000. *T. Alberts, J. H. Ainsworth and F. Warburton.*

PORTER BROS. (DIES & MOULDS), 4 Frederick Road, Edgbaston, Birmingham 11. November 14. £100. *H. W. Porter and C. H. Porter.*

RIGBY'S (OLDHAM) LTD., Ironmonger Lane, Oldham. November 15. £2,000. *To carry on bus. of pattern and tool makers in light engineering, etc. W. F. Kemp, C. Walker and G. Wright.*

METALS RESEARCH, 91 King Street, Cambridge. November 15. £15,000. *Dr. M. Cole, J. Moores and T. P. Hoar.*

WOODCOCK & BOOTH, Woodvale Brass Works, Brighouse, Yorks. November 15. £7,500. *To carry on bus. of brassfounders, ironfounders, etc. C. E. Woodcock and Mrs. D. Woodcock.*

TURNER TOOLS & ENGINEERING CO., 40-43 Brasshouse Lane, Smethwick, Staffs. November 18. £3,000. *T. Turner and J. T. Bloxham.*

MARINE GEARS, 13 Barstow Square, Wakefield. November 20. £1,000. *To carry on bus. of gear cutters and makers, etc. N. W. Carlton and Mrs. H. Carlton.*

KEMPT PRECISION TOOLING, 37 Junction Road, Croydon, Surrey. November 20. £1,000. *To carry on bus. of iron masters, founders and workers, manufacturers of and dealers in forgings, castings, tools, etc. R. R. R. Kempt and Mrs. O. E. A. Kempt and R. H. Kempt.*

VARCO, 22 Parsonage, Manchester 3. November 25. £10,000. *To carry on bus. of precision engineers, etc. R. A. Walsh, H. Wynters and R. Wilson.*

R. HEMMINGFIELD, Station Road, South Bank, Middlesbrough. November 27. £2,000. *To carry on bus. of ironfounders, steel makers, refiners and rollers, etc. R. Hemmingfield and Mrs. J. O. Hemmingfield and Winifred Hemmingfield.*

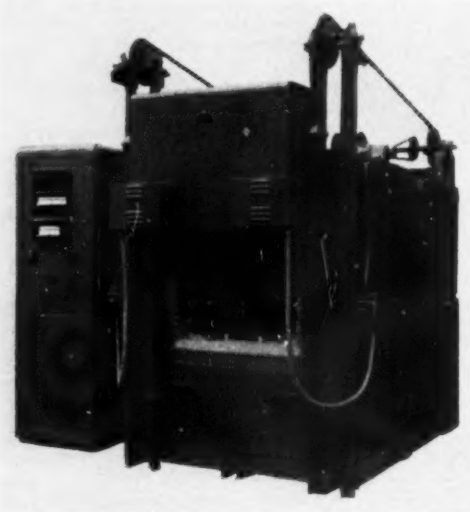
R. H. H. FRANKS, 2 Guildford Street, Chertsey. November 29. £10,000. *To carry on bus. of engineers, foundry workers, etc. R. H. H. Franks and Evelyn R. M. Franks.*

FARNHAM BROS., 56-60 Greenhill Grove, Manor Park, E.12. December 2. £2,000. *To carry on bus. of metal and alloy makers, machinery merchants, etc. S. Farnham, A. Farnham and W. H. Francis.*

A. W. J. SAUNDERS, 358 London Road, Isleworth, Middlesex. December 2. £700. *To carry on bus. of ironfounders and workers, steel makers, etc. A. W. J. Saunders and Margaret Byfield.*

D.S.S., 116 Old Broad Street, E.C.2. December 4. £100. *To carry on bus. of manufacturers of alloy tool steels, alloy steel castings, magnets, etc. C. Surtees and C. J. A. Dixon.*

From the Register compiled by Jordan & Sons Ltd., 16 Chancery Lane, London, W.C.2.



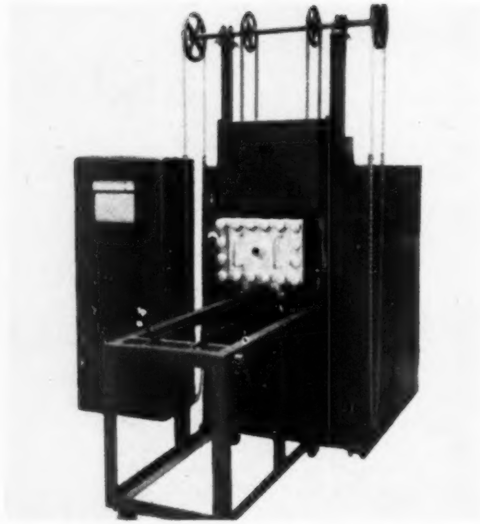


Fig. 3 (*a*) (*above*).—*A heavy duty box-type furnace having a maximum working temperature of* 1,150°C., *and Fig.* 3 (*b*) (*right*).—*A typical atmosphere and vacuum unit for use with the furnace*

longed periods of dry running. Standard types have been successfully subjected to Air Ministry acceptance tests.

Furnaces and an Atmosphere Container

A general purpose heavy duty box-type unit is now included in the range of furnaces manufactured by Hedin Ltd., Commerce Estate, South Woodford, London, E.18.

The illustration Fig. 3 (a) shows a typical example, with internal dimensions of 54 in. by 24 in. by 18 in. It is rated at 60 kW., and has a maximum working temperature of 1,150°C.

Features worth noting are the press-button operated door, non-distorting hearth and efficient thermal insulation. The heating elements are in heavy section 80-20 nickel-chromium and operate on a low voltage via a transformer. Elements are fitted into the door, as well as the walls of the heating chamber, to ensure an even temperature throughout.

The temperature control is fully automatic and includes safety devices such as an indicating controller which can be set a few degrees above the operating temperature, thus providing a protection for the charge as well as the heating elements. A further safety measure is the inclusion of a second contactor, which takes over in the event of the contacts sticking on the operating contactor. There is also an E.A.C. single-phase preventor. In the event of one phase being affected, this instrument immediately cuts the other two phases to prevent an out-of-balance load. The whole of this equipment is housed in a floor cubicle.

The furnaces are now available with a complete range of atmosphere and vacuum containers for the treatment of non-ferrous or special metals. The unit illustrated in Fig. 3 (b) is a typical example and is shown complete with container and charging trolley. The furnace shown in this illustration is the hand-operated version of the range. When the furnaces are used in conjunction with an atmosphere or vacuum, the containers are designed to suit whatever application is required. For example, if a hydrogen or nitrogen atmosphere is to be used, the trolley is equipped with the necessary gauges, and accommodation is provided on the trolley for gas cylinders, to provide a self-contained unit that can be completely removed for cooling purposes, leaving the furnace free for another charge. Typical applications for container-work are bright annealing, de-gassing, copper brazing and sintering.

Flame-failure Equipment

The FSM4 flame-failure and ignition programming control unit recently announced by Elcontrol Ltd., 10 Wyndham Place, London, W.1, is a fully automatic controller for use with practically any automatically initiated industrial oil- or gas-burning equipment.

The unit makes use of an infra-red cell as the flame detector, and embodies an a.c. amplifier so that it responds only to the fluctuating infra-red radiation characteristic of all flames and is not affected by glowing refractory.

Although the FSM4 is a fully automatic controller embodying a programming motor switch assembly, it is of the same size as other standard Elcontrol units—13 in. by 8 in. by 6 in.—and is housed in a standard Elcontrol steel case with hinged lid. It is also supplied in chassis form, or in a weatherproof cast iron or aluminium box. The chassis is readily withdrawable.

The FSM4 is for use with burners having direct spark ignition or spark-ignited gas or light oil pilots which may either remain on or be switched off after establishment of the main flame, and it operates in conjunction with various types of temperature control.

The unit enforces a fully-safe lighting-up sequence, including initial fan start-up, pre-purge period, fixed 'failure-to-ignite' time, and automatic shut-down and lock-out on running-flame failure and on failure to light up within the programmed time. Used in conjunction with oil pre-heat arrangements, it can control the ignition temperature sequence.

Ergonomics in Metal Industries

THE word ' ergonomics ' is a post-war addition to the English language, states W. F. Floyd, B.Sc., Ph.D., in the course of a paper on the subject presented to the Institution of Mechanical Engineers. It was coined in 1950 by a group of workers, including engineers, to express in one word the application of anatomical, physiological and psychological knowledge to the study of man and his working environment, a field of research which had become increasingly important during the 1939-45 war. It would be wrong to give the impression that the invention of a new word has meant the development of a new science. Rather it is the grouping of existing biological sciences under the single idea of the man-machine relationship, with the orientation towards engineering design problems, which is new.

Biological Approach

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SITUATIONS VACANT

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Applicants must be conversant with modern drop forge technique and be experienced in die design and able to control labour. The situation offers excellent prospects for the right type of man, is permanent and progressive, and a good superannuation scheme is available.

Write, giving full particulars of past experience, positions held, etc., in chronological order, to Box FW 100, *Metal Treatment and Drop Forging*.

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MINISTRY OF SUPPLY Military Engineering Experimental Establishment, Christchurch, Hants., require Senior Scientific Officer to supervise work and development of materials testing and metallographical laboratory, to investigate metallurgical problems arising from development and testing of military equipment, and to undertake research on application of ferrous and non-ferrous alloys to this equipment. Quals., 1st or 2nd class Hons. degree in Metallurgy or equiv., and experience in materials testing. Knowledge of welding an advantage. Salary, £1,130—£1,330. Women's pay slightly less. Equal-pay scheme. Forms from M.L.N.S., Technical and Scientific Register (K), 26 King Street, London, S.W.1, quoting F648/7A.

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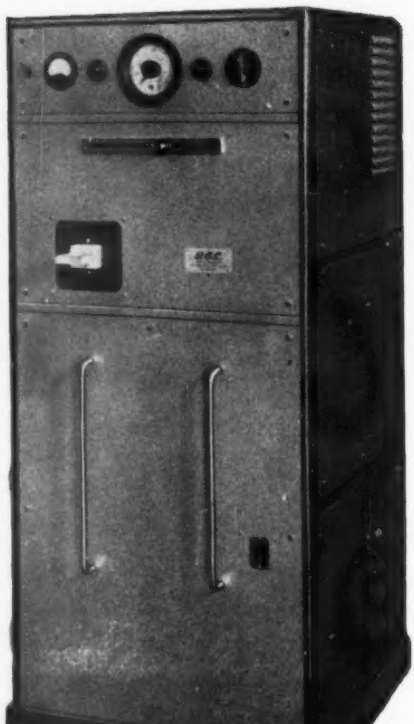

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metal treatment and Drop Forging

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